127600-3-F

Final Report

AN ANALYSIS OF SPECTRAL MEASUREMENT DATA FOR MULTISPECTRAL REMOTE SENSING TO DETECT JOJOBA PLANTS

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NOTICES

Sponsorship The work reported herein was conducted by the Environmental Research Institute of Michigan (formerly the Willow Run Laboratory of The University of Michigan) for the Drug Enforcement Agency, Washington D. C. under Contract Number DEA-77-6. The Project Manager was Stanley Green.

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16. Abstract

This report presents the results of a program to measure and analyze the spectral signature characteristics of jojobas and various associated arid land vegetation types. Laboratory spectral measurements of leaves and field measurements of plants are presented. The Suits canopy model has been applied to account for the significant differences observed between the laboratory and field measured spectral signature characteristics. A multispectral signature study has been conducted to analyze the potential for using a multispectral sensor system to locate populations of jojobas across large areas of the Southwest United States.

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PREFACE

This report presents the results of a measurement and analysis program to determine the multispectral signature characteristics of the jojoba plant.

This report is submitted in fulfillment of Contract DEA-77-6 with the Drug Enforcement Agency. The principal investigator for the program is Dr. J. Robert Maxwell of the Infrared and Optics Division of the Environmental Research Institute of Michigan. The work was performed under the overall direction of Mr. R. R. Legault, Vice President of ERIM and Head of the IRO Division. Very significant contributions to this program were made by Blake Arnold and Richard Valade in preparing and operating the instrumentation in the field, and by Margaret Schall in writing the computer program for reducing and analyzing the measurement data. Dr. G. Suits provided computer programs for vegetative canopy modeling and false alarm calculations.

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1.0

INTRODUCTION AND SUMMARY

A program of laboratory and ground-based field spectral measurements and analysis has been conducted to determine the multispectral signature of the jojoba plant and the associated types of arid land vegetation. The objective of the program is to assess the potential of multispectral remote sensing to locate jojoba plants across large areas of Arizona and New Mexico.

The major finding on this program is that the multispectral signature of jojobas is not very distinctive from that of several other types of vegetation commonly found in the area. Creosote, dahlia, and an unidentified scrub have spectral signatures most like that of the jojobas, followed by cholla, desert broom, prickly pear, and mesquite. Most arid land plants have small and relatively thick leaves, and they are not very densely foliated. As a consequence, their reflectances in the field all tend to be quite low and quite similar.

On the basis of the measurements and analyses conducted on this program, it is clear that the spectral signature characteristics of jojobas are not sufficiently unique that jojobas can be located with a high probability of detection and low probability of false alarm just on the basis of spectral signature characteristics alone. The multispectral sensor would appear to offer the best potential as a screening sensor. As such the output of the multispectral sensor would be processed automatically and used to eliminate from consideration large areas with no jojobas. Photo interpretation would be used to definitively identify the presence of jojobas in areas where the multispectral sensor would give detections of jojobas and plants with very similar spectral characteristics. Used in this manner, the multispectral sensor could potentially decrease the amount of photo-interpretation required to map jojoba populations very significantly.

In order to assess the potential for cost savings by using the multispectral sensor as a screening sensor, it would be necessary to collect and process some actual airborne multispectral sensor data to obtain accurate estimates for probability of detection and false alarm.

Thus the potential roles of multispectral sensing and photographic sensing for locating and inventorying jojobas in a large area survey are identified as a result of this study.

- A multispectral scanner is potentially useful as a means for surveying large areas for the purpose of discriminating between those areas that may contain jojoba plants and those that do not. The multispectral scanner and processor will not be able to unambiguously discriminate jojoba plants from several other desert plants, but it may be a valuable way to eliminate very large areas that do not contain jojobas from a more detailed photographic survey. It is recommended that a limited multispectral scanner flight test program be conducted to evaluate the potential for using a multispectral scanner and processor to identify areas likely to contain jojobas and to discriminate against those large land areas do not.

- Photographic interpretation will be necessary for the actual detection of jojoba plants. A possible photo-interpreter resource might be classes of high school students in those areas whose lands are being surveyed with instruction given as part of the classwork.

Section 2 of this report presents the results of the laboratory spectral measurements of jojobas and associated arid land vegetation types. Section 3 presents the results of actual ground-based measurements of plants in the field, and the multispectral signature analysis is discussed in Section 4.

2.0

LABORATORY MEASUREMENTS

2.1 INSTRUMENTATION

Laboratory reflectances and transmittances of individual leaf samples were measured in Tucson, Arizona, May 11 and 12, 1977, with a Beckman DK-2 spectrophotometer. Leaf and bark samples were taken from plants in the field and brought into the laboratory and measured within two hours of cutting. Previous measurements have shown that reflectances and transmittances do not change in this period of time [Reference 1]. The Beckman DK-2 is a dual beam instrument that operates from 0.4 to 1.1 μm with a photomultiplier detector and from 0.9 to 2.6 μm with a PbS detector. A tungsten lamp is used as a source and a quartz prism disperses energy in the monochrometer. A sample is placed in the path of one beam for transmission measurements and the ratio of energy in the two beams is recorded on an X-Y plotter. An integrating sphere is used for reflectance measurements and the ratio is recorded of energy in one beam reflected from the sample to that in the other beam reflected from a white standard. The standard used for these measurements is an Eastman $BaSO_4$ white reference with a reflectance greater than 0.98 from 0.325 to 1.3 μm and decreasing to 0.70 at 2.5 μm as determined by comparison with published and accepted values for the reflectance of MgO. The slit width varies to keep the energy in the reference beam constant, hence the spectral resolution varies with wavelength. The spectral resolution of the reflectance and transmittance measurements is 5 nm at 0.4 μm, 2.5 nm at 0.7 μm, and 3.5 nm at 1.0 μm with the photomultiplier; and 10 nm

[1] Record of Measurement Program, J. Robert Maxwell, June 1977, Report 127600-1-T prepared for contract DEA-77-6.

at 1.0 μm, 20 nm at 2.0 μm, and 35 nm at 2.5 μm with the PbS detector. The repeatability of the reflectance measurements is 1% of full scale. The absolute accuracy of the reflectance measurements is estimated to be 2% for low reflectance surfaces and 5% for high reflectance surfaces.

2.2 DATA REDUCTION

Chart records of reflectance and transmittance vs wavelength were digitized with a CALMA 480 X-Y digitizer at wavelength increments of approximately 0.5 nm. A data reduction program corrects reflectance relative to $BaSO_4$ to absolute reflectance; corrects the wavelength calibration of the instrument to a calibration based on a standard Dydimium filter with known absorption lines; and defines reflectance and transmittance values at increments of 5 nm. This corresponds to the highest resolution obtainable with the Beckman DK-2 and is consistent with the limiting accuracy of the CALMA digitizer. A magnetic tape has been prepared with all of the measurement data including titles with the type of plant measured, the date of measurement, the spectral range covered by the measurement (0.4 to 1.1 μm or 2.0 to 2.6 μm), the measurement condition (top or underside of leaf, reflectance or transmission), and all other significant information pertinent to the measurements.

2.3 LABORATORY MEASUREMENT DATA SUMMARY

Laboratory spectral measurements were made on 10 varieties of vegetation. These include jojoba, prickly pear, acacia, cholla, desert broom, mesquite, palo verde, dahlia, creosote, and an unknown variety of plant found in the Tucson area near the jojobas. Thirty-one complete (0.4 to 2.5 μm) laboratory spectra were obtained. Table 2-1 is a summary of the laboratory measurement data presented in Figures 2-1 to 2-30. Black tape was used to back leaves when reflectances were measured, and the reflectance of the tape is seen to be very low throughout the spectral range of interest.

The spectral reflectances of leaves of the various types of vegetation included in Figures 2-1 to 2-30 show spectral characteristics common to all vegetation, namely minima at 0.675 μm and 0.4 μm due to absorption by chlorophyll in all leaves, with a high reflectance beyond about 0.7 μm. In the near infrared, beyond 0.7 μm, the absorption in the leaf is relatively small so that both reflection and transmittance are quite high. The presence of chlorophyll in the jojoba nuts and in the bark of the palo verde is obvious.

There are quite significant differences in the spectral reflectances of the leaves of the different varieties of plants, for example the high reflectance of the prickly pear in the near infrared (Figure 2-11) and the high reflectance of the cholla in the visible relative to the reflectance of the jojoba leaf. It is important, however, to note that the reflectance of a plant in the field is a function of several parameters of which the leaf spectra are only one. The density of the foliage, the geometrical characteristics of the plant, and the sun and view angles are also important parameters as will be shown with the field measurement data presented in Section 3 and as will be discussed in more detail in Section 4.

TABLE 2-1 LABORATORY MEASUREMENT DATA SUMMARY

				Figure Number
REFL		TUCSON, FEMALE JOJOBA LEAF		
CRUS	60202	VIS,REF, JOJOBA LEAF 1, FEMALE	(TUCSON) 5/11/77	
X	60200	VIS,REF, JOJOBA LEAF 2, FEMALE	(TUCSON) 5/11/77	
SQUA	61200	VIS,REF, JOJOBA II, FEMALE, INSIDE OF CURL	(TUCSON) 5/11/77	2.1
DIAM	61201	VIS,REF, JOJOBA II, FEMALE, OUTSIDE OF CURL	(TUCSON) 5/11/77	
REFL		TUCSON, FEMALE JOJOBA LEAF		
CRUS	60301	IR, REF, JOJOBA LEAF 1, FEMALE	(TUCSON) 5/11/77	
X	60302	IR, REF, JOJOBA LEAF 2, FEMALE	(TUCSON) 5/11/77	
SQUA	61100	IR, REF, JOJOBA II, FEMALE, INSIDE OF CURL	(TUCSON) 5/11/77	2.2
DIAM	61101	IR, REF, JOJOBA II, FEMALE, OUTSIDE OF CURL	(TUCSON) 5/11/77	
TRAN		TUCSON, FEMALE JOJOBA LEAF		
CRUS	60606	VIS,TRN, JOJOBA LEAF 3, FEMALE	(TUCSON) 5/11/77	
X	60605	VIS,TRN, JOJOBA LEAF 4, FEMALE	(TUCSON) 5/11/77	2.3
SQUA	61202	VIS,TRN, JOJOBA II	(TUCSON) 5/11/77	
TRAN		TUCSON, FEMALE JOJOBA LEAF		
CRUS	60506	IR, TRN, JOJOBA LEAF 3, FEMALE	(TUCSON) 5/11/77	
X	60505	IR, TRN, JOJOBA LEAF 4, FEMALE	(TUCSON) 5/11/77	2.4
SQUA	61102	IR, TRN, JOJOBA II	(TUCSON) 5/11/77	
REFL		TUCSON, MALE JOJOBA LEAF		
CRUS	60601	VIS,REF, JOJOBA LEAF 3, MALE	(TUCSON) 5/11/77	
X	60600	VIS,REF, JOJOBA LEAF 4, MALE	(TUCSON) 5/11/77	2.5
REFL		TUCSON, MALE JOJOBA LEAF		
CRUS	60500	IR, REF, JOJOBA LEAF 3, MALE	(TUCSON) 5/11/77	
X	60502	IR, REF, JOJOBA LEAF 4, MALE	(TUCSON) 5/11/77	2.6
TRAN		TUCSON, MALE JOJOBA LEAF		
CRUS	60603	VIS,TRN, JOJOBA LEAF 1, MALE	(TUCSON) 5/11/77	
X	60604	VIS,TRN, JOJOBA LEAF 2, MALE	(TUCSON) 5/11/77	2.7
TRAN		TUCSON, MALE JOJOBA LEAF		
CRUS	60503	IR, TRN, JOJOBA LEAF 1, MALE	(TUCSON) 5/11/77	
X	60504	IR, TRN, JOJOBA LEAF 2, MALE	(TUCSON) 5/11/77	2.8
REFL		TUCSON, JOJOBA BARK + NUTS		
CRUS	60201	VIS,REF, JOJOBA NUTS	(TUCSON) 5/11/77	
X	60602	VIS,REF, JOJOBA BARK	(TUCSON) 5/11/77	2.9
REFL		TUCSON, JOJOBA BARK + NUTS		
CRUS	60501	IR, REF, JOJOBA BARK	(TUCSON) 5/11/77	
X	60300	IR, REF, JOJOBA NUTS	(TUCSON) 5/11/77	2.10
REFL		TUCSON, PRICKLEY PEAK		
CRUS	60100	VIS,REF, PRICKLEY PEAR	(TUCSON) 5/11/77	2.11

TABLE 2-1 (Continued)

				Figure Number
REFL		TUCSON, PRICKLEY PEAR		
CRUS	60400	IR, REF, PRICKLEY PEAR	(TUCSON) 5/11/77	2.12
REFL		TUCSON, MESQUITE		
CRUS	60101	VIS,REF, MESQUITE BARK	(TUCSON) 5/11/77	
X	60102	VIS,REF, MESQUITE 1	(TUCSON) 5/11/77	2.13
SQUA	60103	VIS,REF, MESQUITE 2	(TUCSON) 5/11/77	
REFL		TUCSON, MESQUITE		
CRUS	60401	IR, REF, MESQUITE BARK	(TUCSON) 5/11/77	
X	60403	IR, REF, MESQUITE 1	(TUCSON) 5/11/77	2.14
SQUA	60402	IR, REF, MESQUITE 2	(TUCSON) 5/11/77	
REFL		TUCSON, SCOTCH NO 88 TAPE		
CRUS	60104	VIS,REF, SCOTCH NO 88 TAPE	(TUCSON) 5/11/77	2.15
REFL		TUCSON, SCOTCH NO 88 TAPE		
CRUS	60404	IR, REF, SCOTCH NO 88 TAPE	(TUCSON) 5/11/77	2.16
REFL		TUCSON, BLUE PALO VERDE		
CRUS	60700	VIS,REF, BLUE PALO VERDE, YELLOW FLOWERS	(TUCSON) 5/11/77	
X	60703	VIS,REF, BLUE PALO VERDE BARK	(TUCSON) 5/11/77	2.17
SQUA	60705	VIS,REF, BLUE PALO VERDE LEAVES AND STEMS	(TUCSON) 5/11/77	
REFL		TUCSON, BLUE PALO VERDE		
CRUS	60805	IR, REF, BLUE PALO VERDE, YELLOW FLOWERS	(TUCSON) 5/11/77	
X	60804	IR, REF, BLUE PALO VERDE BARK	(TUCSON) 5/11/77	2.18
SQUA	60800	IR, REF, BLUE PALO VERDE LEAVES AND STEMS	(TUCSON) 5/11/77	
REFL		TUCSON, ACACIA		
CRUS	60701	VIS,REF, ACACIA BARK	(TUCSON) 5/11/77	2.19
X	60704	VIS,REF, ACACIA LEAF	(TUCSON) 5/11/77	
REFL		TUCSON, ACACIA		
CRUS	60802	IR, REF, ACACIA BARK	(TUCSON) 5/11/77	2.20
X	60801	IR, REF, ACACIA LEAF	(TUCSON) 5/11/77	
REFL		TUCSON, JUMPING CHOLLA		
CRUS	60702	VIS,REF, JUMPING CHOLLA BUD	(TUCSON) 5/11/77	2.21
REFL		TUCSON, JUMPING CHOLLA		
CRUS	60803	IR, REF, JUMPING CHOLLA BUD	(TUCSON) 5/11/77	2.22
REFL		TUCSON, DESERT BROOM		
CRUS	60900	VIS,REF, DESERT BROOM BARK	(TUCSON) 5/11/77	2.23
X	60901	VIS,REF, DESERT BROOM STEMS	(TUCSON) 5/11/77	

TABLE 2-1 (Concluded)

				Figure Number
REFL		TUCSON, DESERT BROOM		
CRUS	61000	IR, REF, DESERT BROOM BARK	(TUCSON) 5/11/77	2.24
X	61001	IR, REF, DESERT BROOM STEMS	(TUCSON) 5/11/77	
REFL		TUCSON, DAHLIA		
CRUS	60902	VIS,REF, DAHLIA STEMS AND BUDS	(TUCSON) 5/11/77	2.25
REFL		TUCSON, DAHLIA		
CRUS	61002	IR, REF, DAHLIA STEMS AND BUDS	(TUCSON) 5/11/77	2.26
REFL		TUCSON, CREOSOTE		
CRUS	60903	VIS,REF, CREOSOTE LEAVES	(TUCSON) 5/11/77	2.27
X	60904	VIS,REF, CREOSOTE BARK	(TUCSON) 5/11/77	
REFL		TUCSON, CREOSOTE		
CRUS	61003	IR, REF, CREOSOTE LEAVES	(TUCSON) 5/11/77	2.28
X	61004	IR, REF, CREOSOTE BARK	(TUCSON) 5/11/77	
REFL		TUCSON, UNKNOWN		
CRUS	60905	VIS,REF, UNKNOWN 2, GREEN LEAVES	(TUCSON) 5/11/77	2.29
X	60906	VIS,REF, UNKNOWN 2, CHLOROTIC LEAVES	(TUCSON) 5/11/77	
REFL		TUCSON, UNKNOWN		
CRUS	61005	IR, REF, UNKNOWN 2, GREEN LEAVES	(TUCSON) 5/11/77	2.30
X	61006	IR, REF, UNKNOWN 2, CHLOROTIC LEAVES	(TUCSON) 5/11/77	

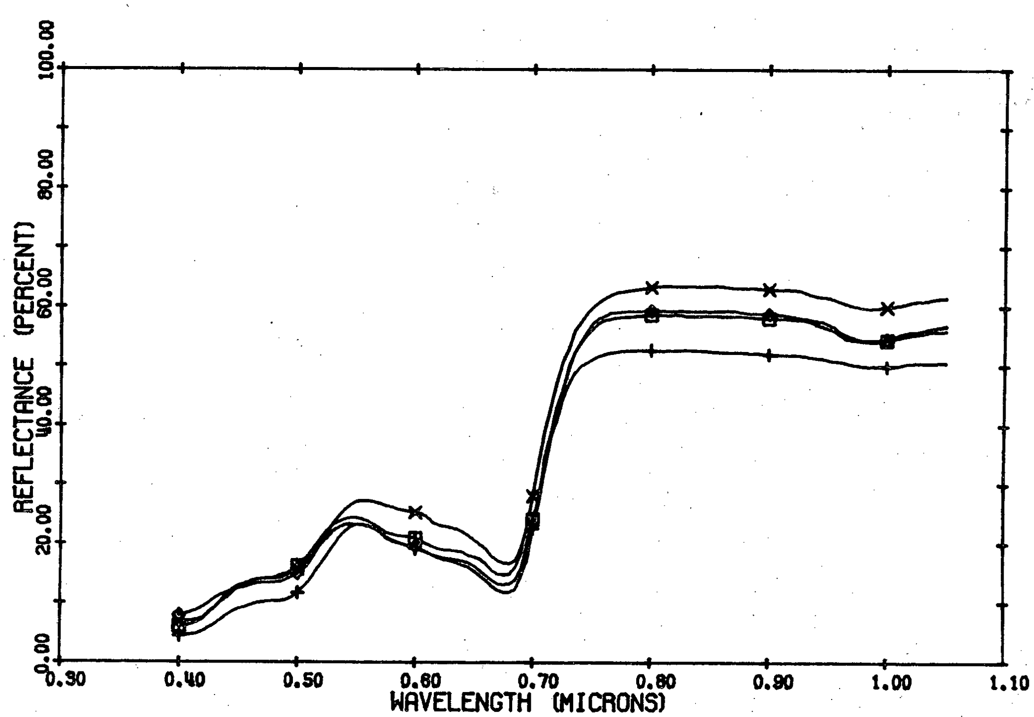

FIGURE 2-1. LABORATORY MEASUREMENTS, FEMALE JOJOBA LEAF.

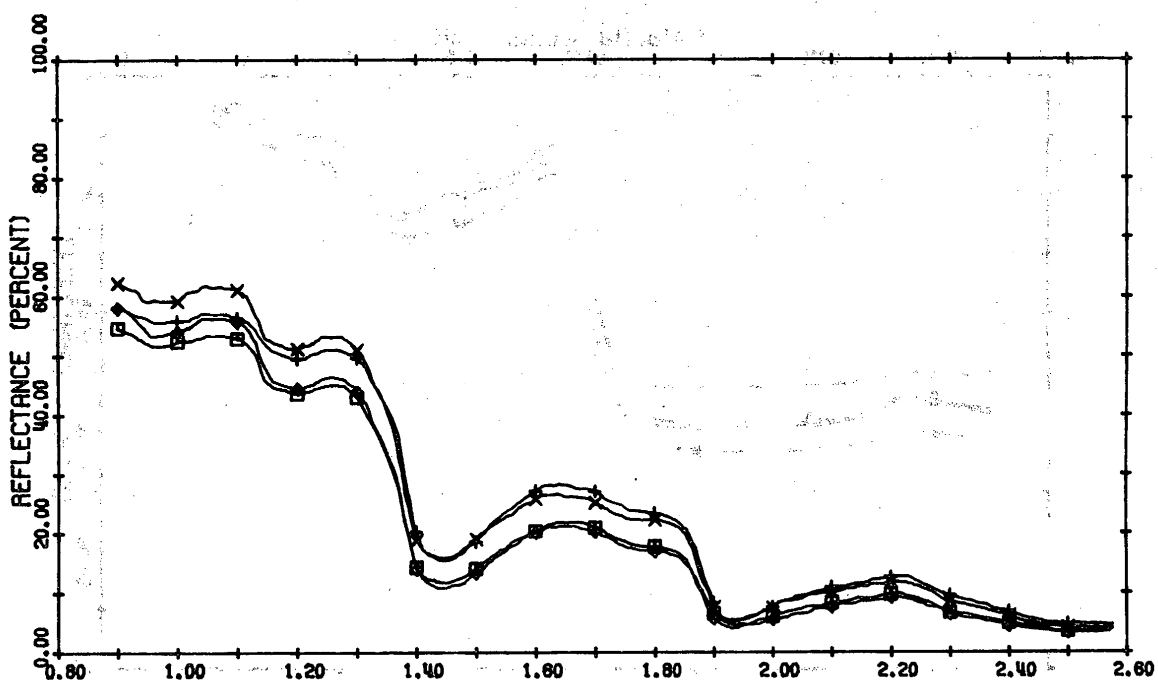

FIGURE 2-2. LABORATORY MEASUREMENTS, FEMALE JOJOBA LEAF.

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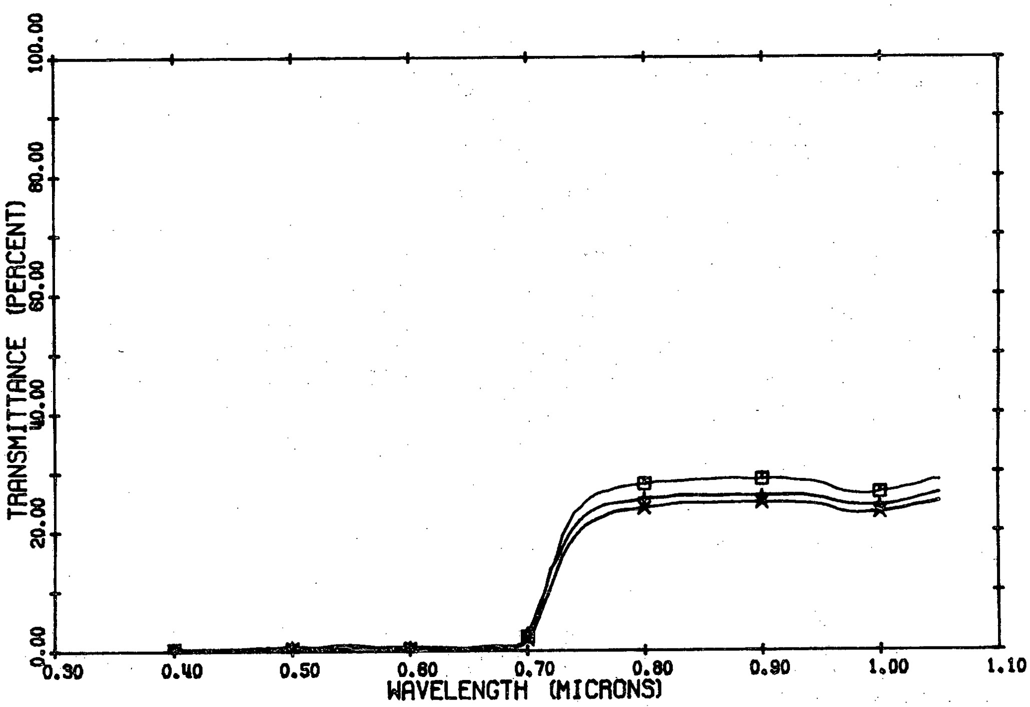

FIGURE 2-3. LABORATORY MEASUREMENTS, FEMALE JOJOBA LEAF.

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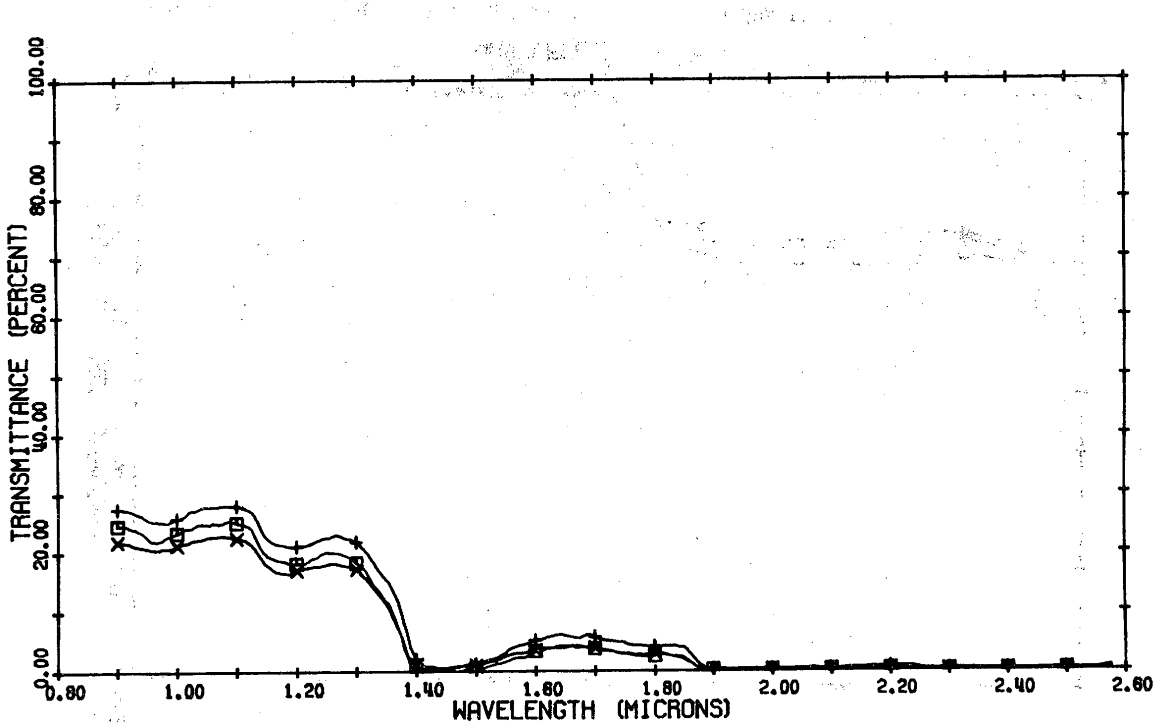

FIGURE 2-4. LABORATORY MEASUREMENTS, FEMALE JOJOBA LEAF.

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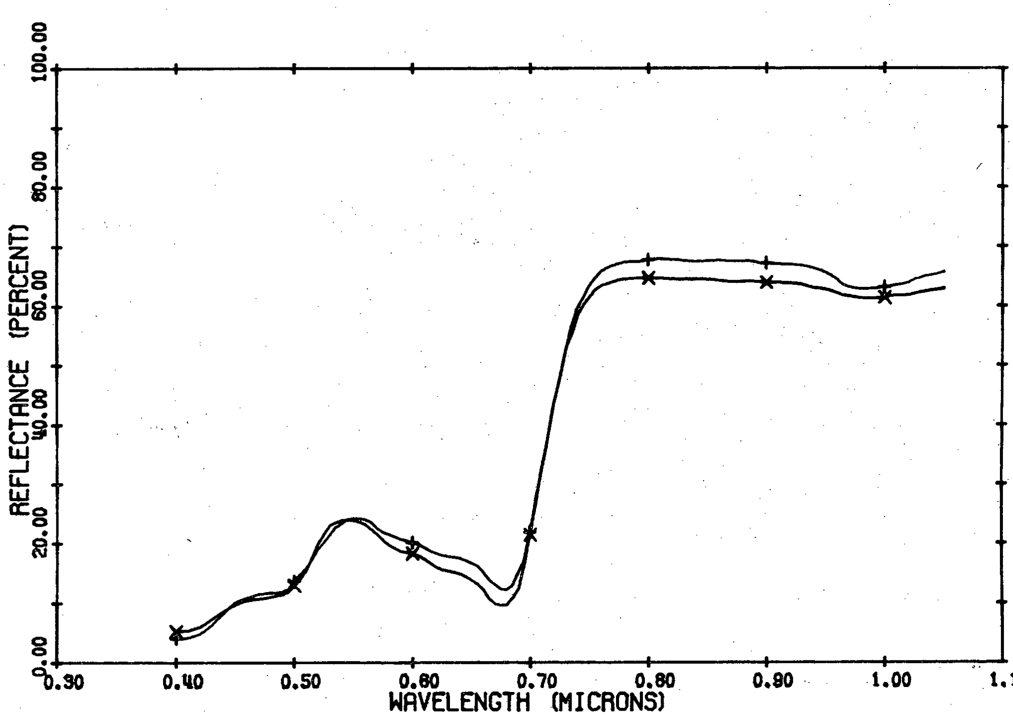

FIGURE 2-5. LABORATORY MEASUREMENTS, MALE JOJOBA LEAF.

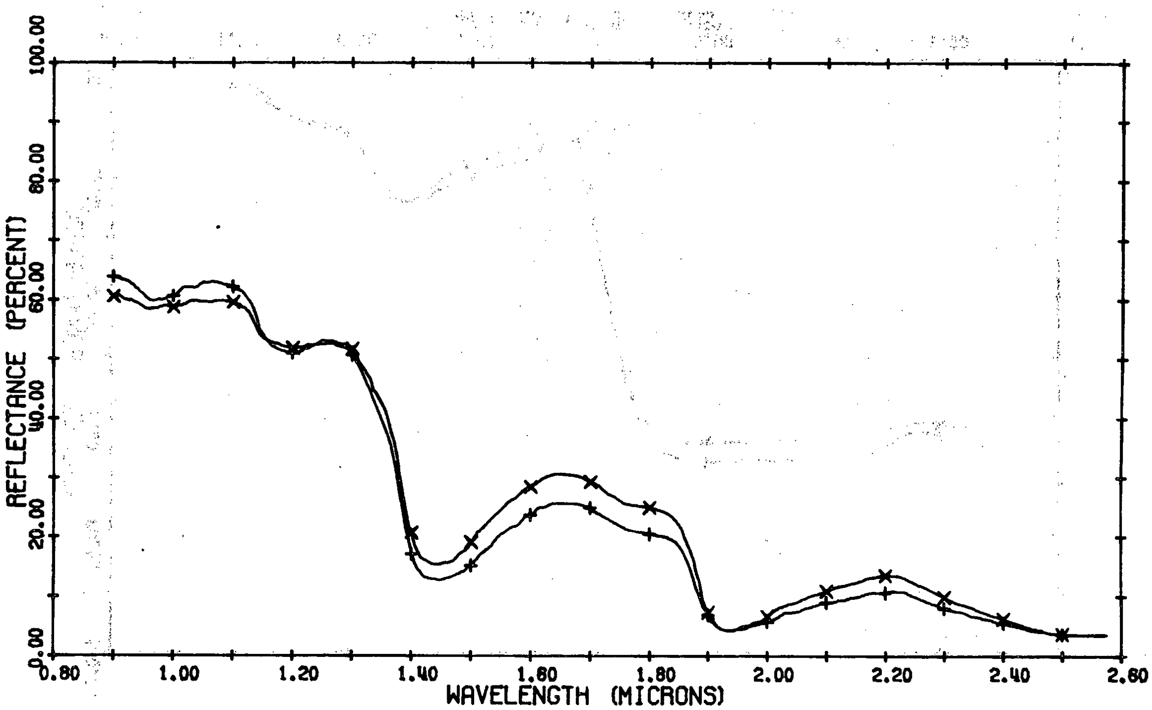

FIGURE 2-6. LABORATORY MEASUREMENTS, MALE JOJOBA LEAF.

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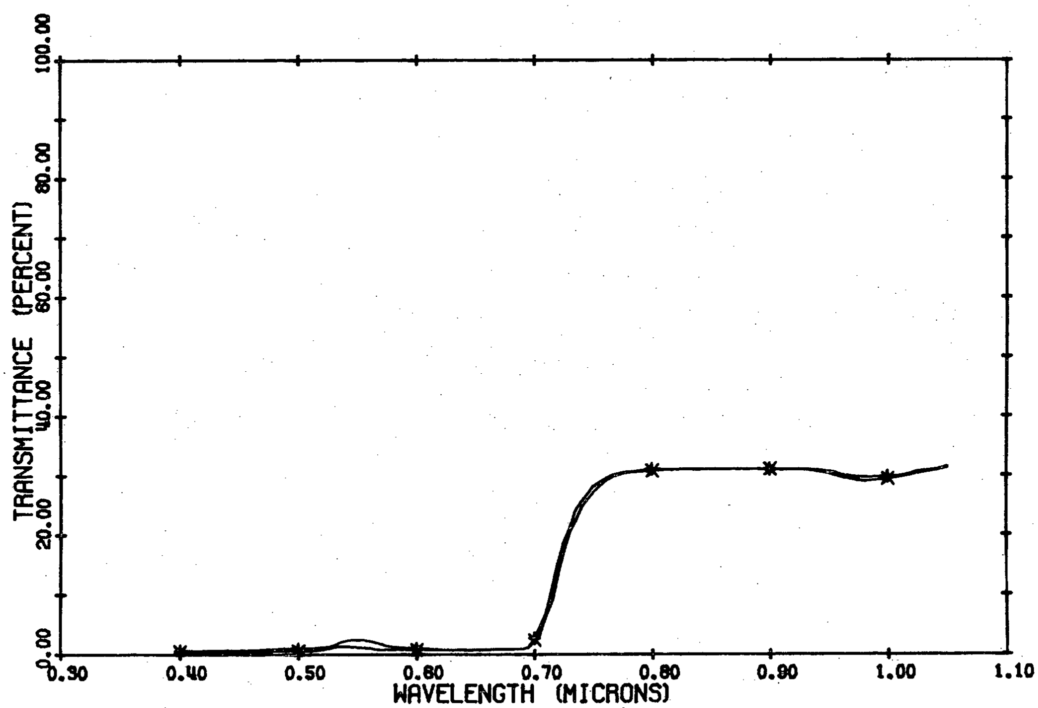

FIGURE 2-7. LABORATORY MEASUREMENTS, MALE JOJOBA LEAF.

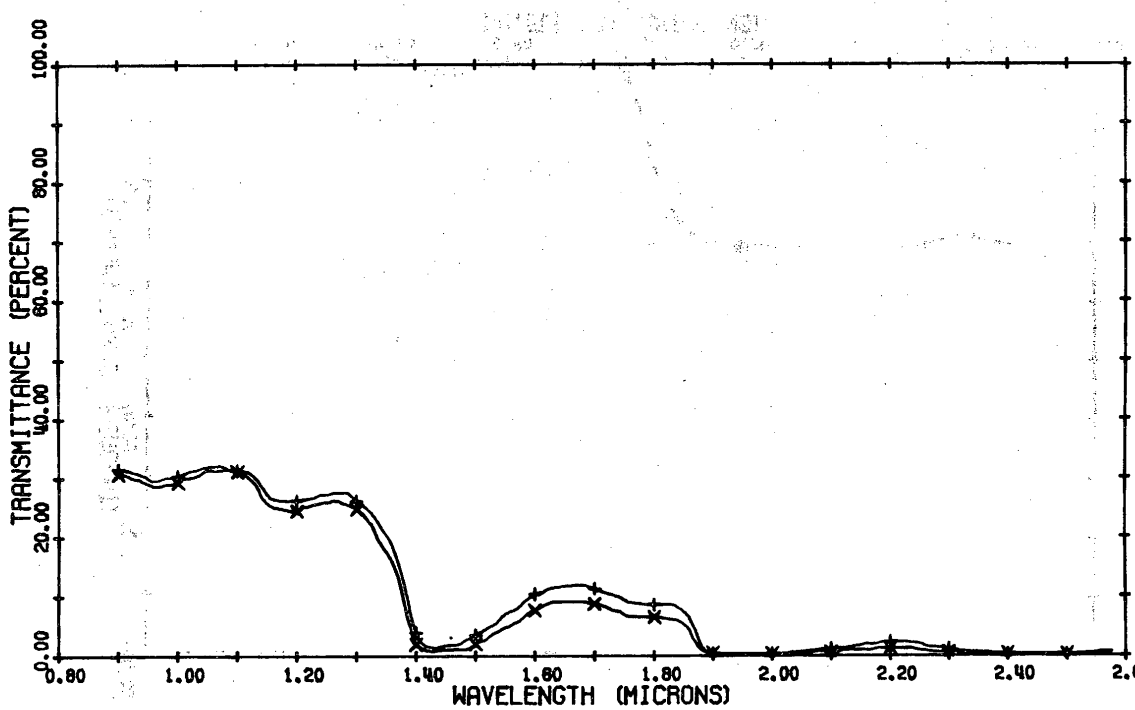

FIGURE 2-8. LABORATORY MEASUREMENTS, MALE JOJOBA LEAF.

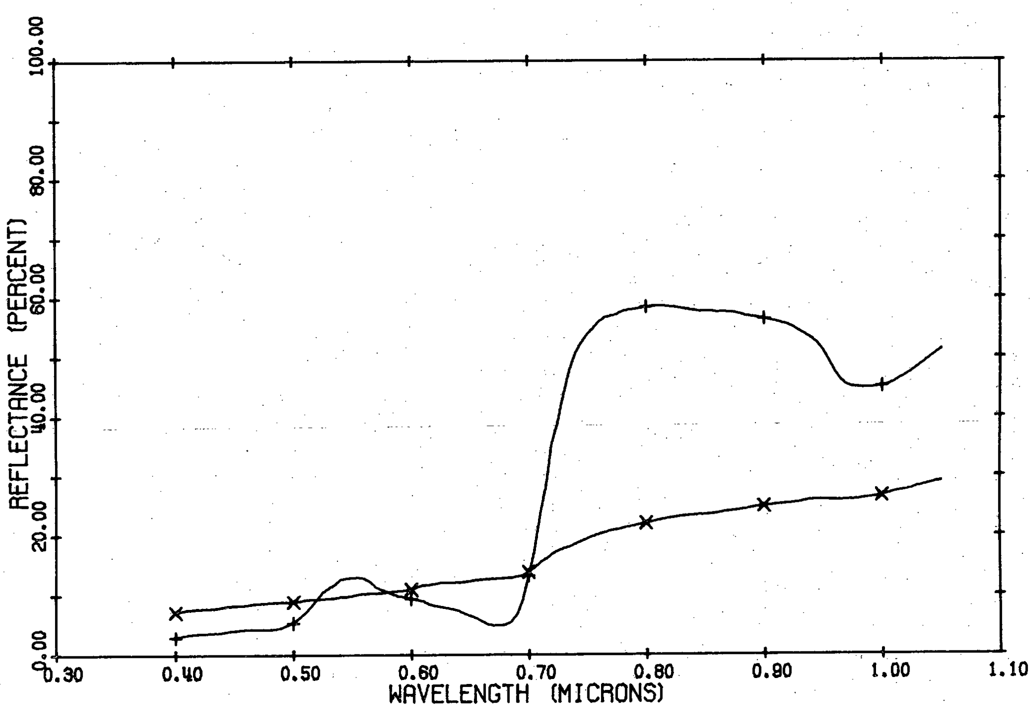

FIGURE 2-9. LABORATORY MEASUREMENTS, JOJOBA BARK AND NUTS.

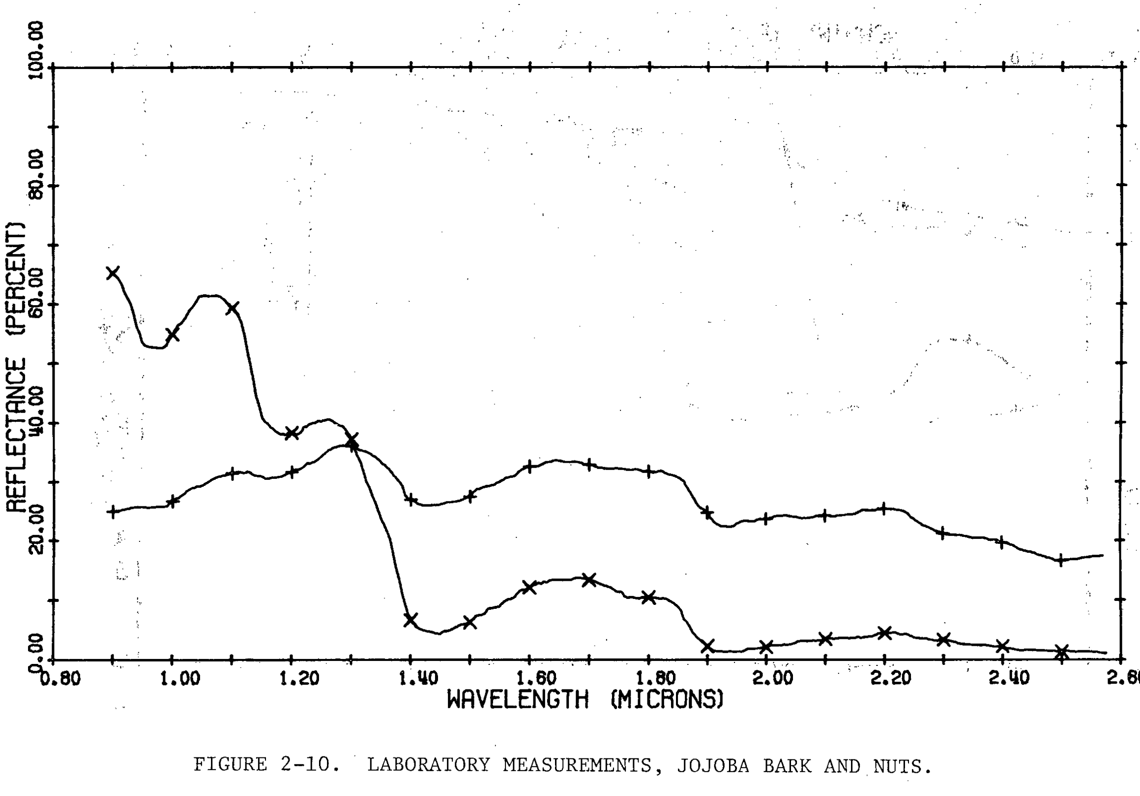

FIGURE 2-10. LABORATORY MEASUREMENTS, JOJOBA BARK AND NUTS.

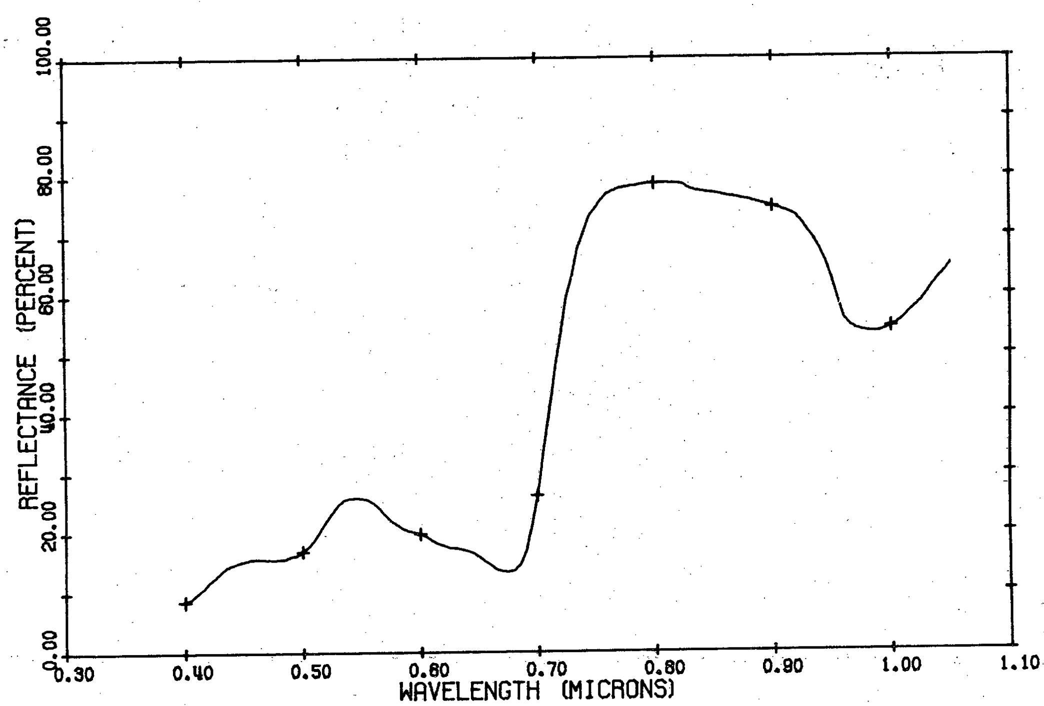

FIGURE 2-11. LABORATORY MEASUREMENTS, PRICKLY PEAR.

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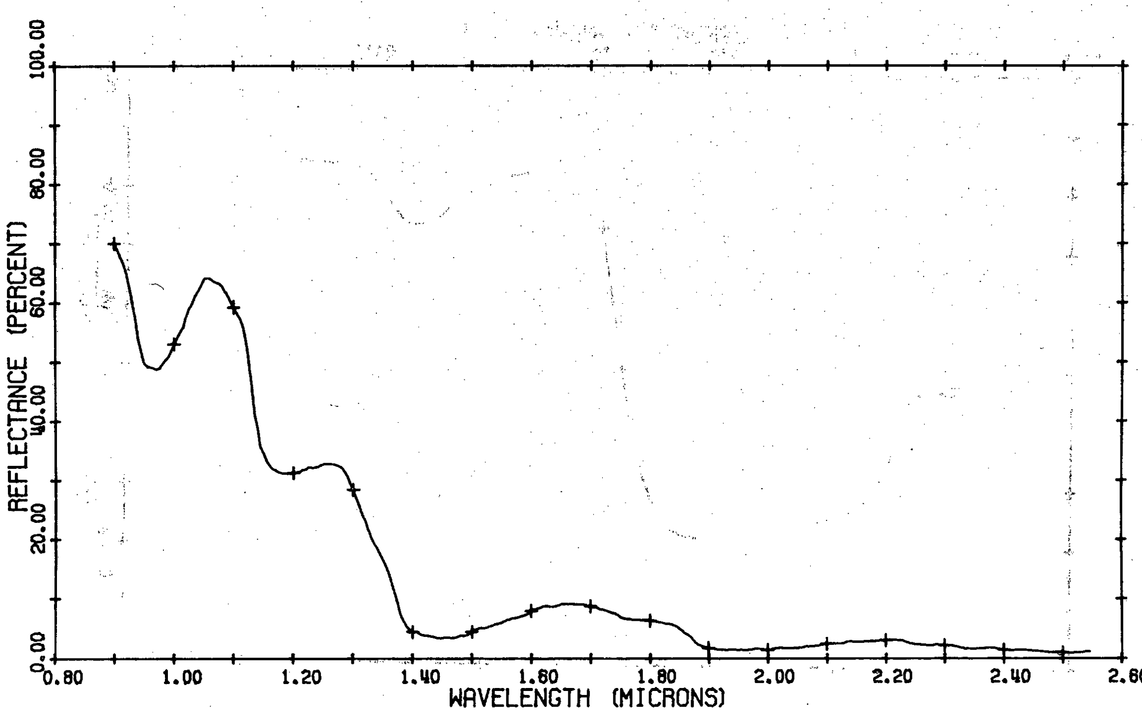

FIGURE 2-12. LABORATORY MEASUREMENTS, PRICKLY PEAR.

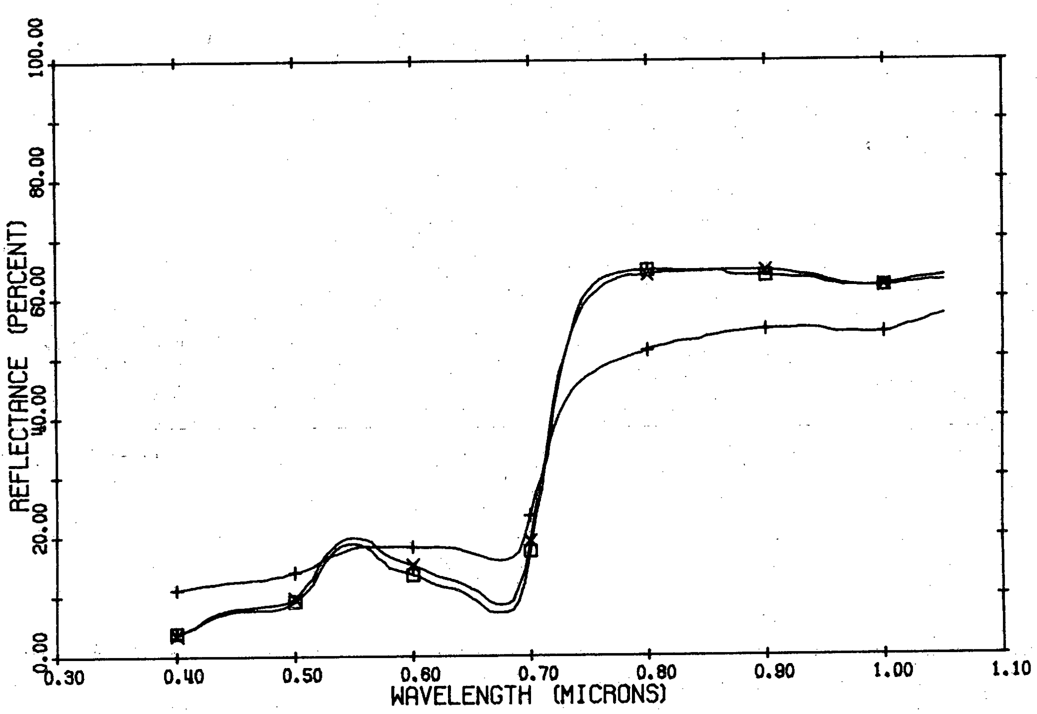

FIGURE 2-13. LABORATORY MEASUREMENTS, MESQUITE.

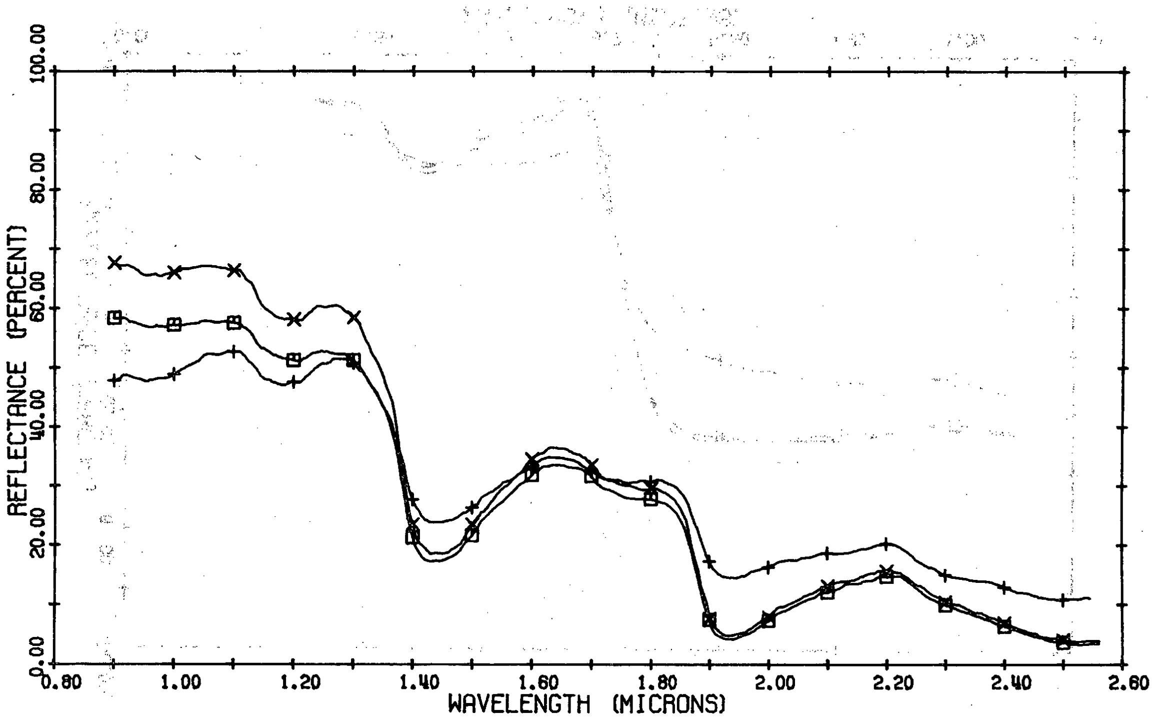

FIGURE 2-14. LABORATORY MEASUREMENTS, MESQUITE.

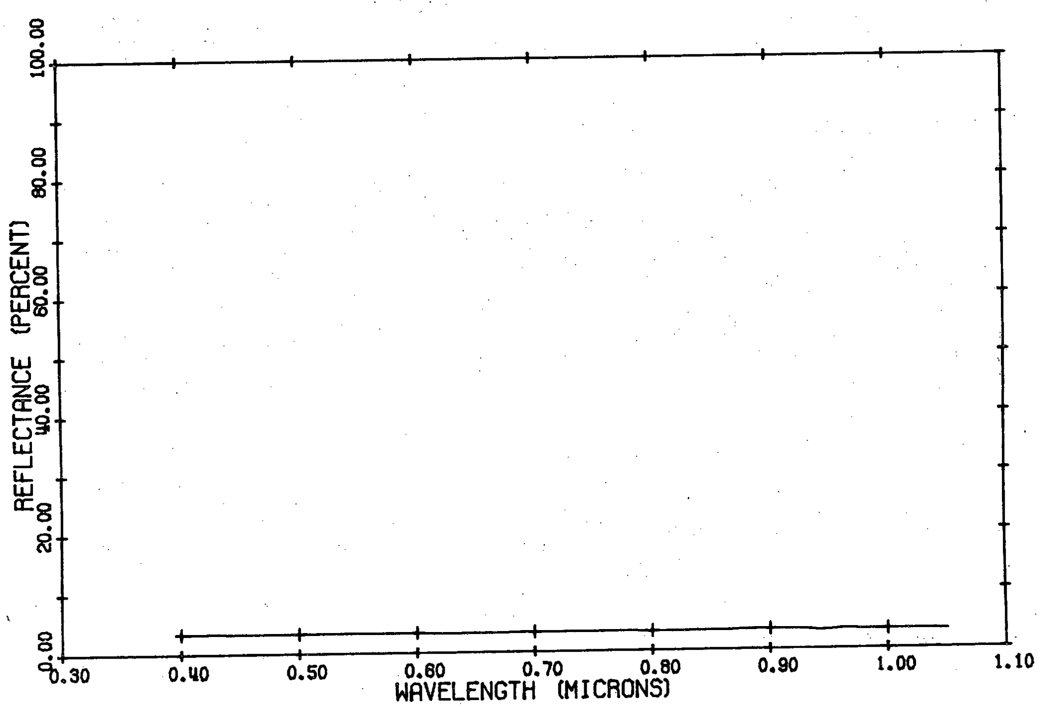

FIGURE 2-15. LABORATORY MEASUREMENTS, SCOTCH NO. 88 TAPE.

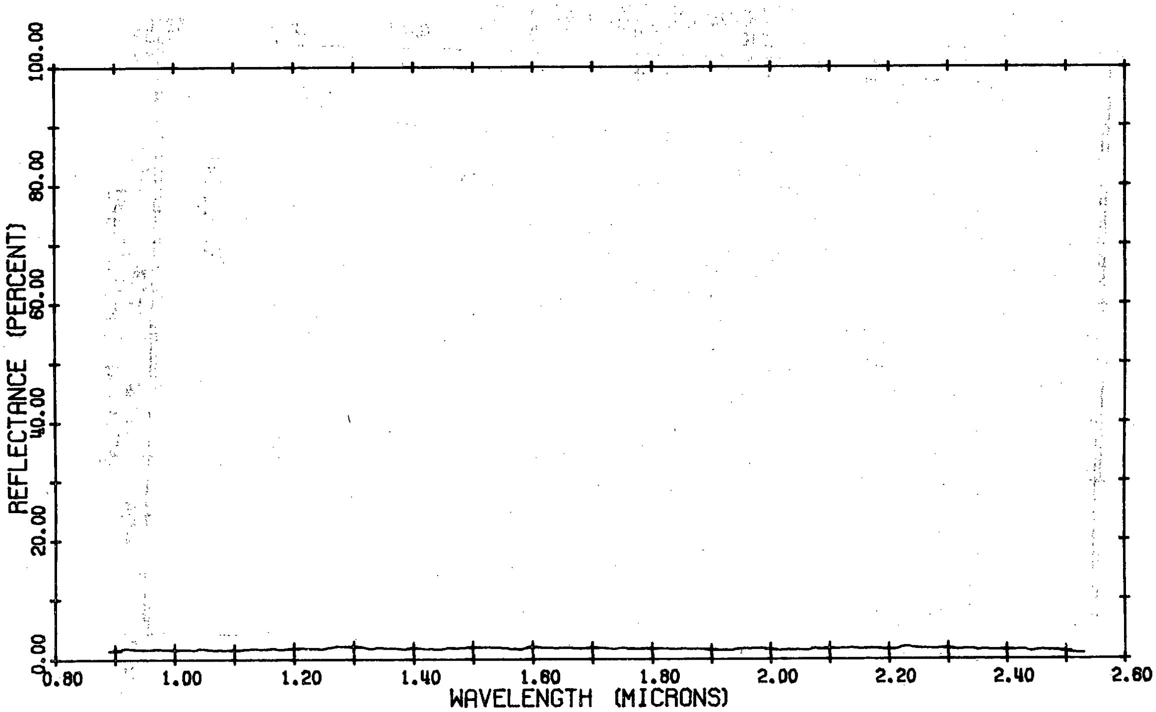

FIGURE 2-16. LABORATORY MEASUREMENTS, SCOTCH NO. 88 TAPE.

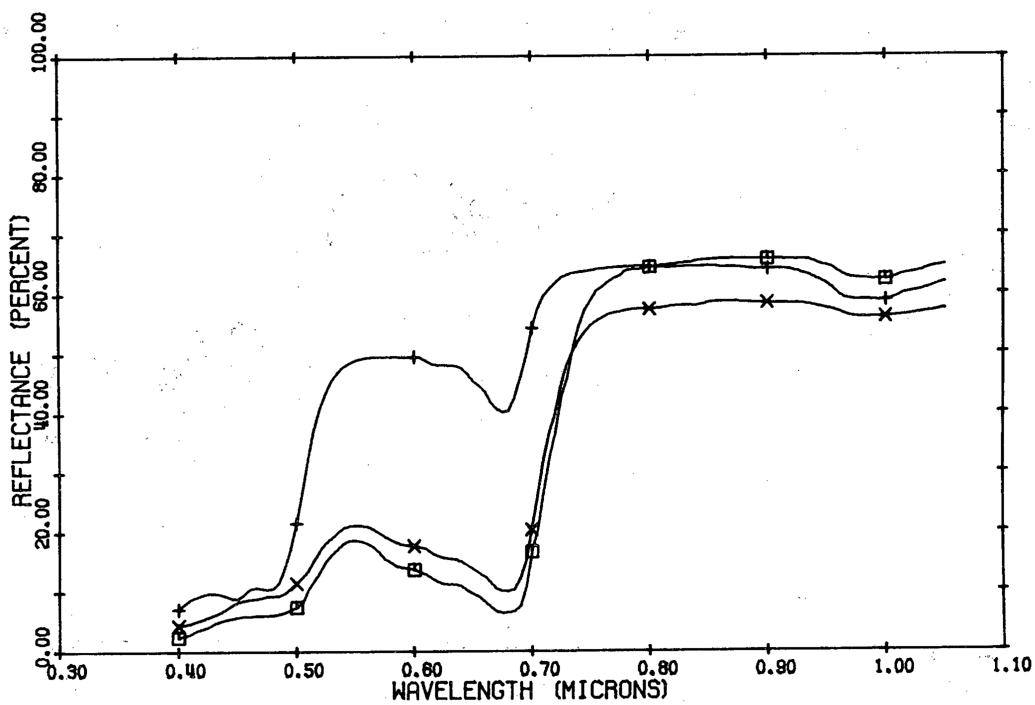

FIGURE 2-17. LABORATORY MEASUREMENTS, BLUE PALO VERDE.

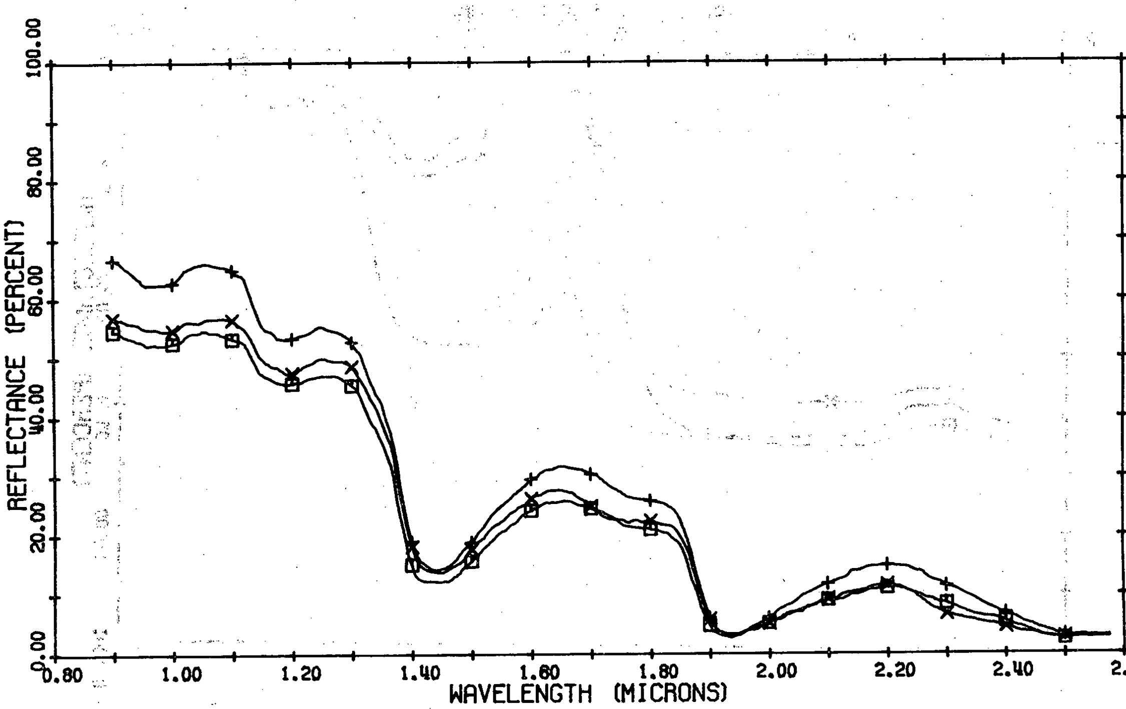

FIGURE 2-18. LABORATORY MEASUREMENTS, BLUE PALO VERDE.

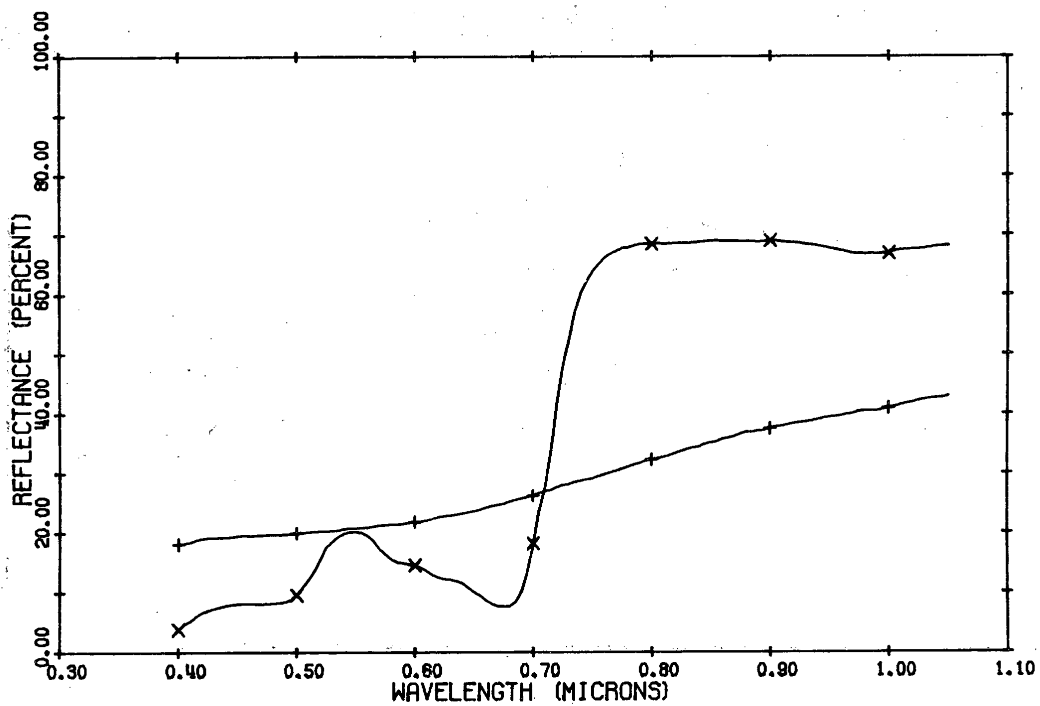

FIGURE 2-19. LABORATORY MEASUREMENTS, ACACIA.

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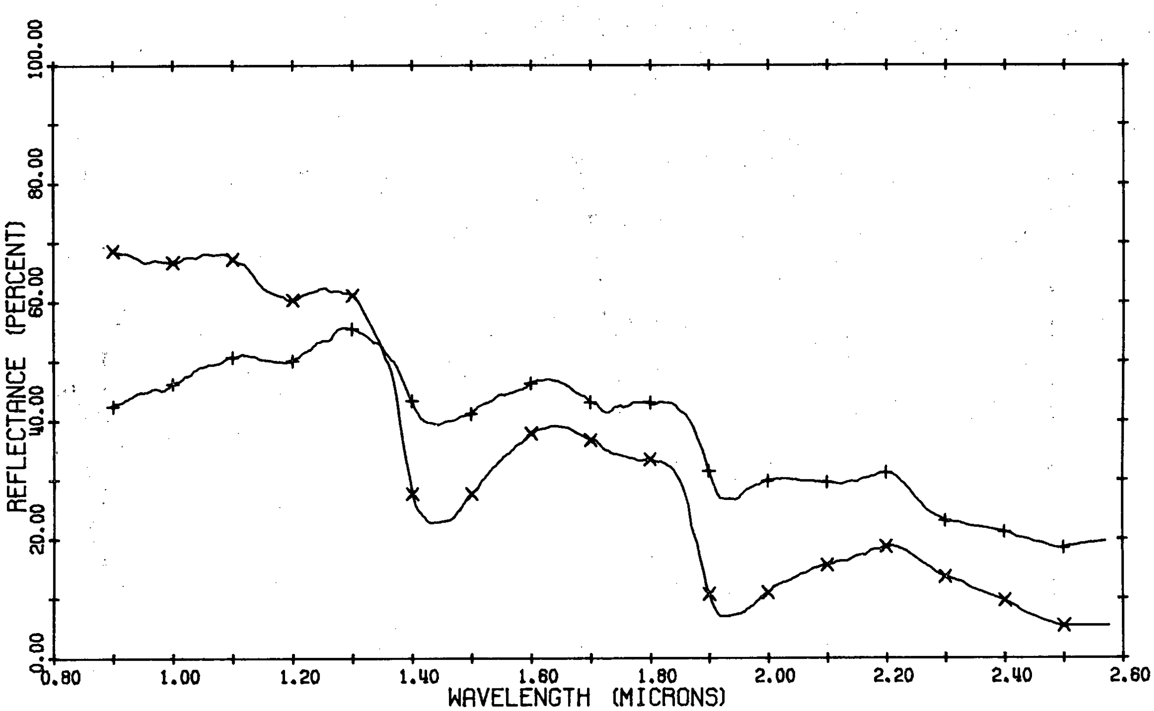

FIGURE 2-20. LABORATORY MEASUREMENTS, ACACIA.

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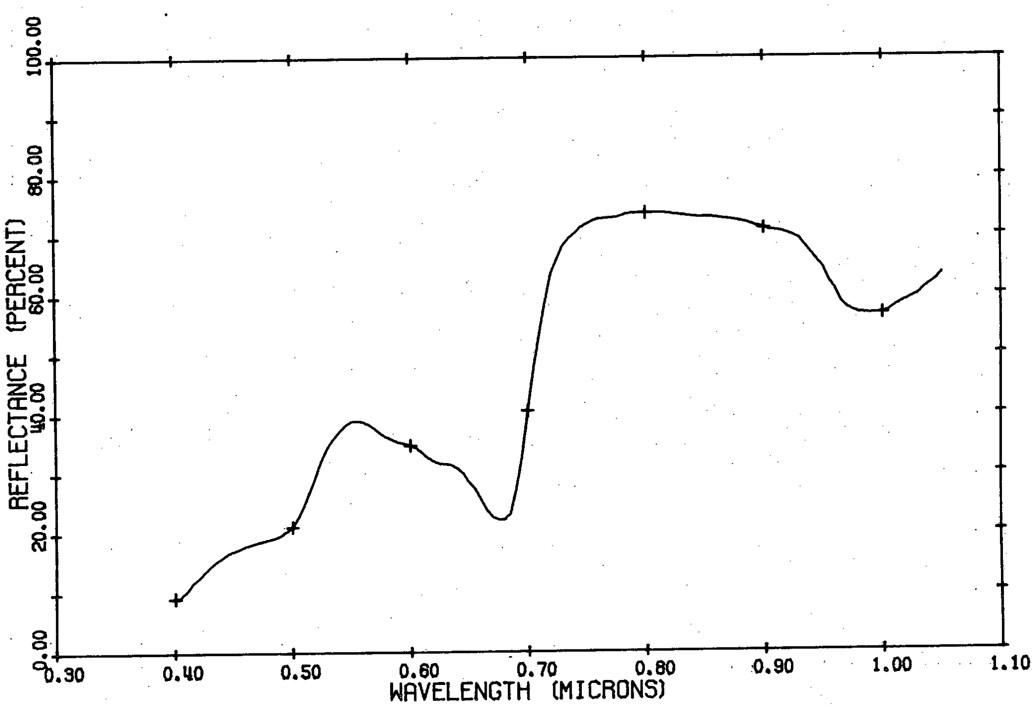

FIGURE 2-21. LABORATORY MEASUREMENTS, JUMPING CHOLLA.

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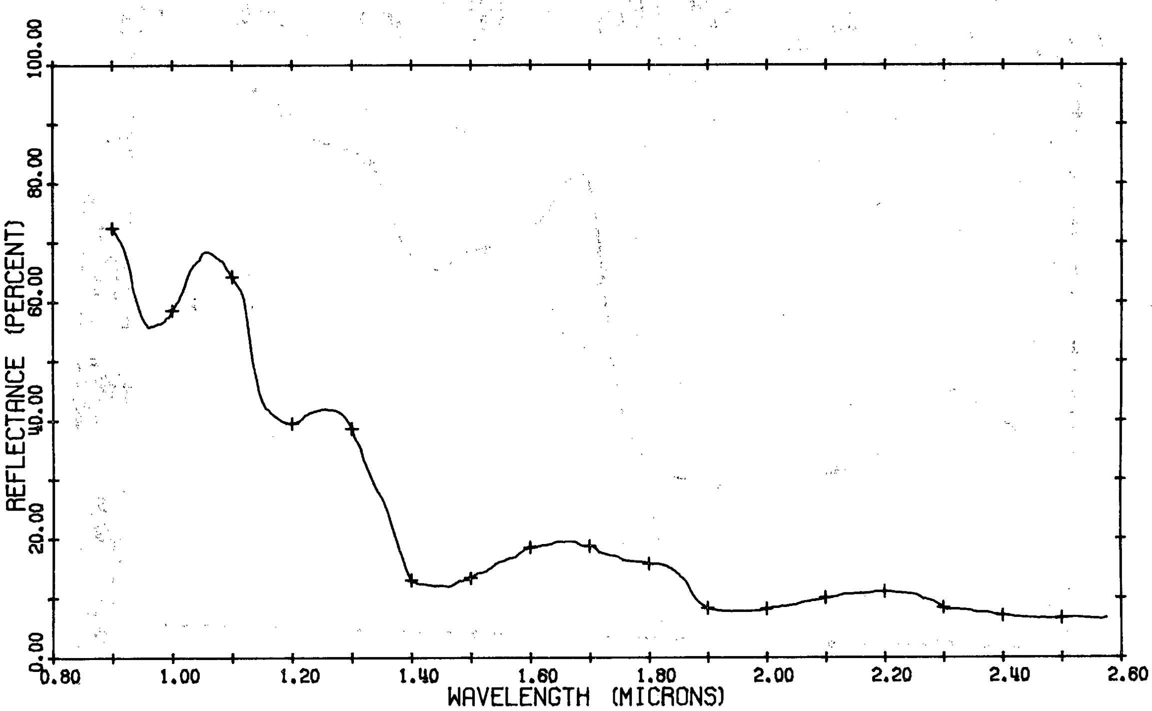

FIGURE 2-22. LABORATORY MEASUREMENTS, JUMPING CHOLLA.

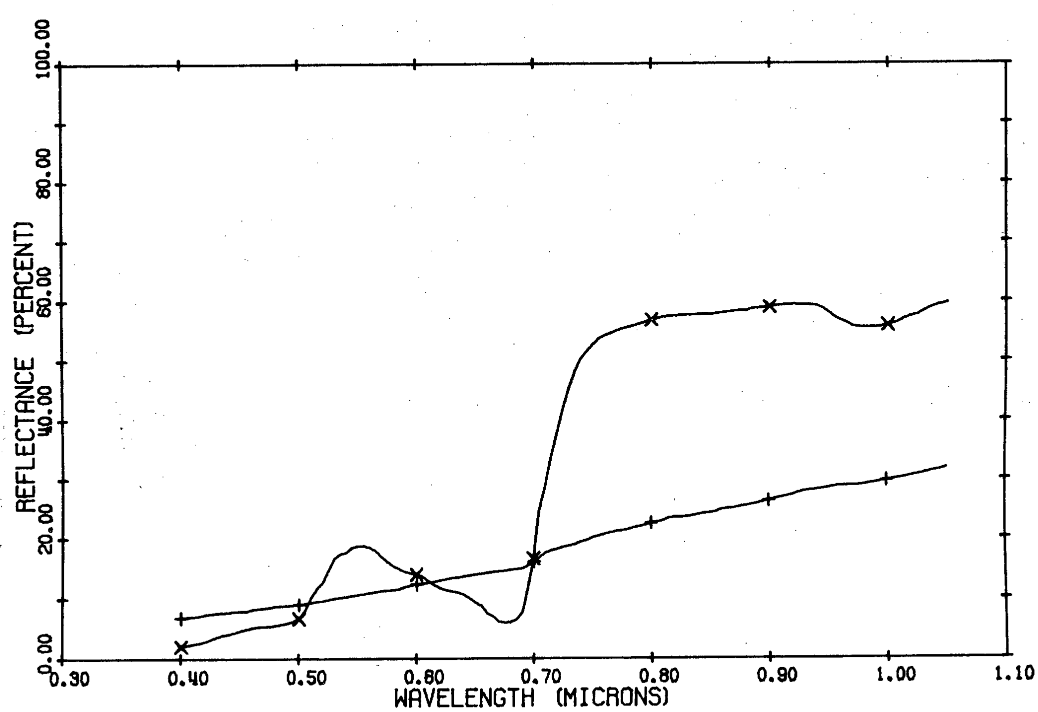

FIGURE 2-23. LABORATORY MEASUREMENTS, DESERT BROOM.

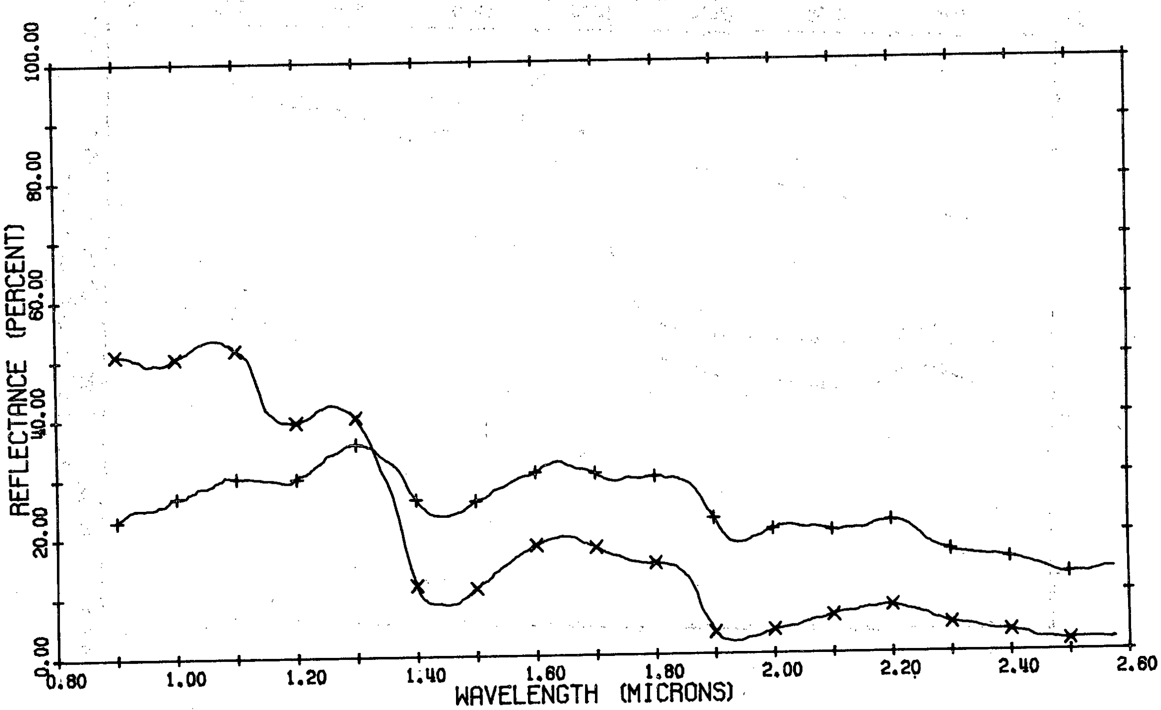

FIGURE 2-24. LABORATORY MEASUREMENTS, DESERT BROOM.

ERIM

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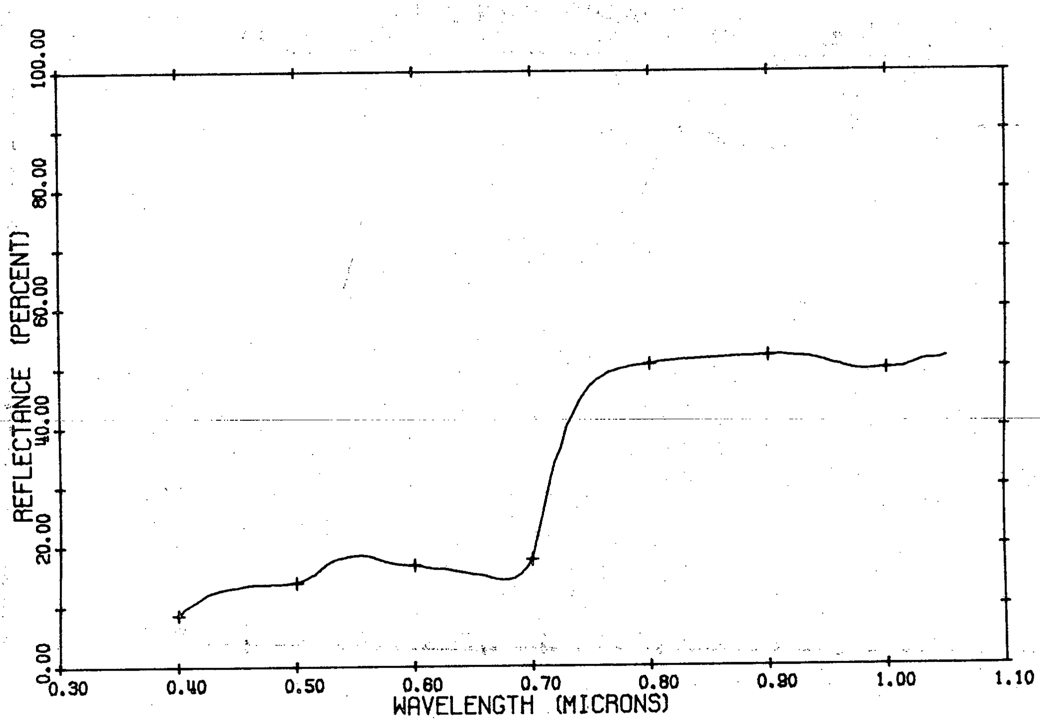

FIGURE 2-25. LABORATORY MEASUREMENTS, DAHLIA.

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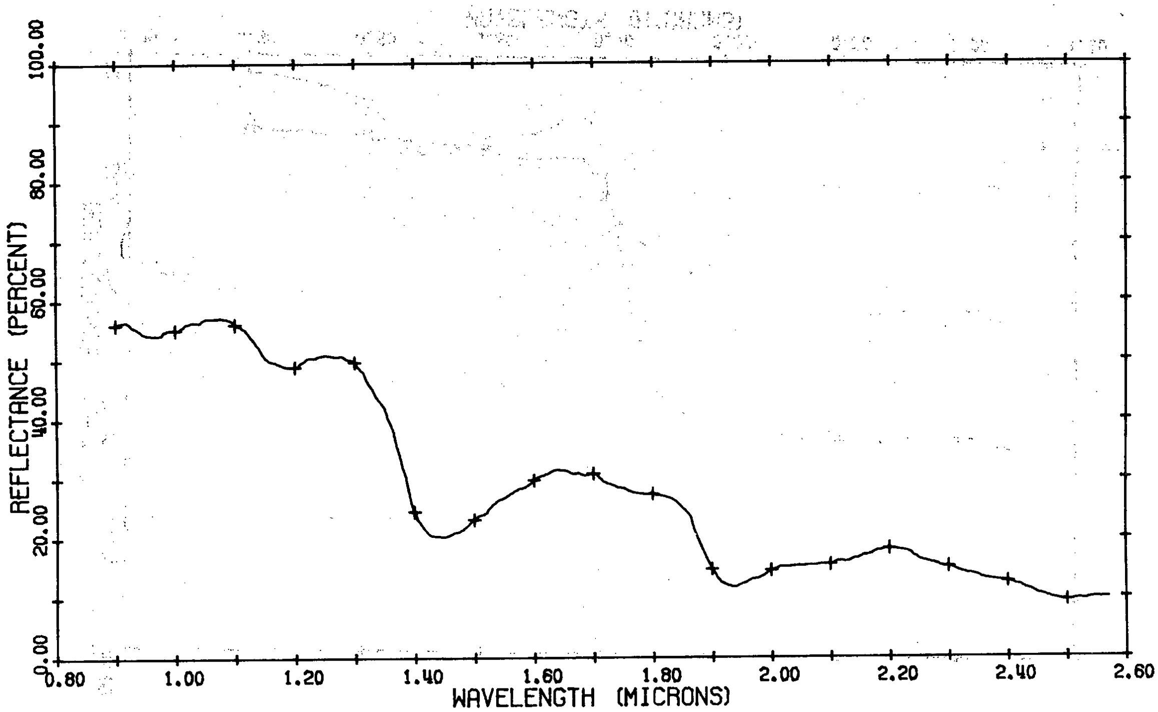

FIGURE 2-26. LABORATORY MEASUREMENTS, DAHLIA.

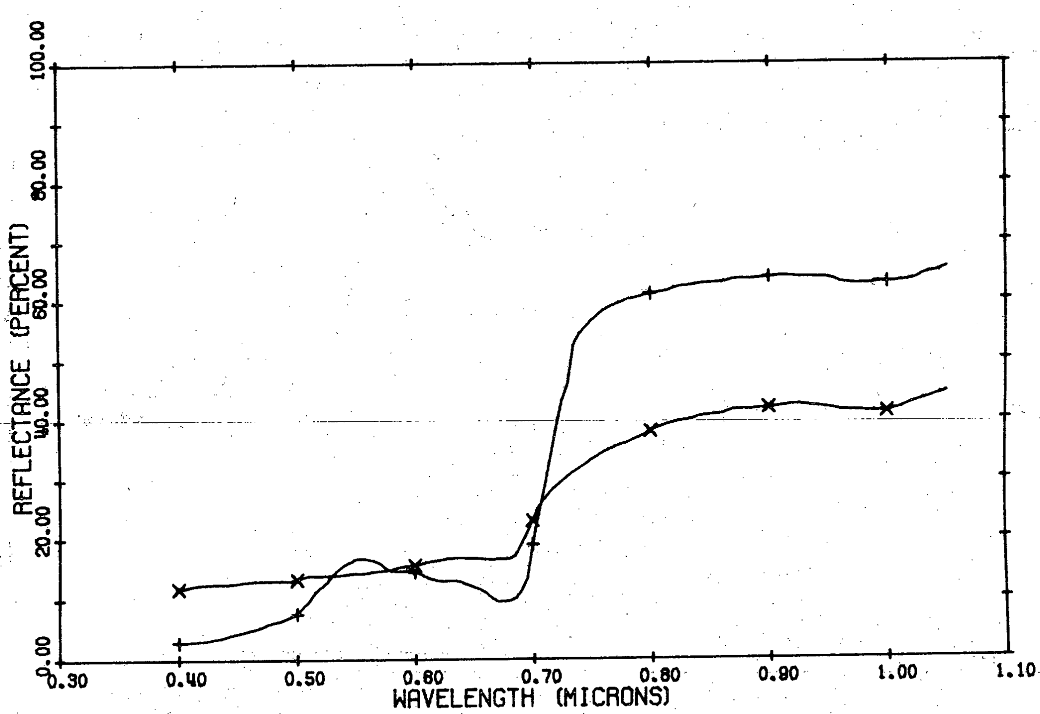

FIGURE 2-27. LABORATORY MEASUREMENTS, CREOSOTE.

ERIM

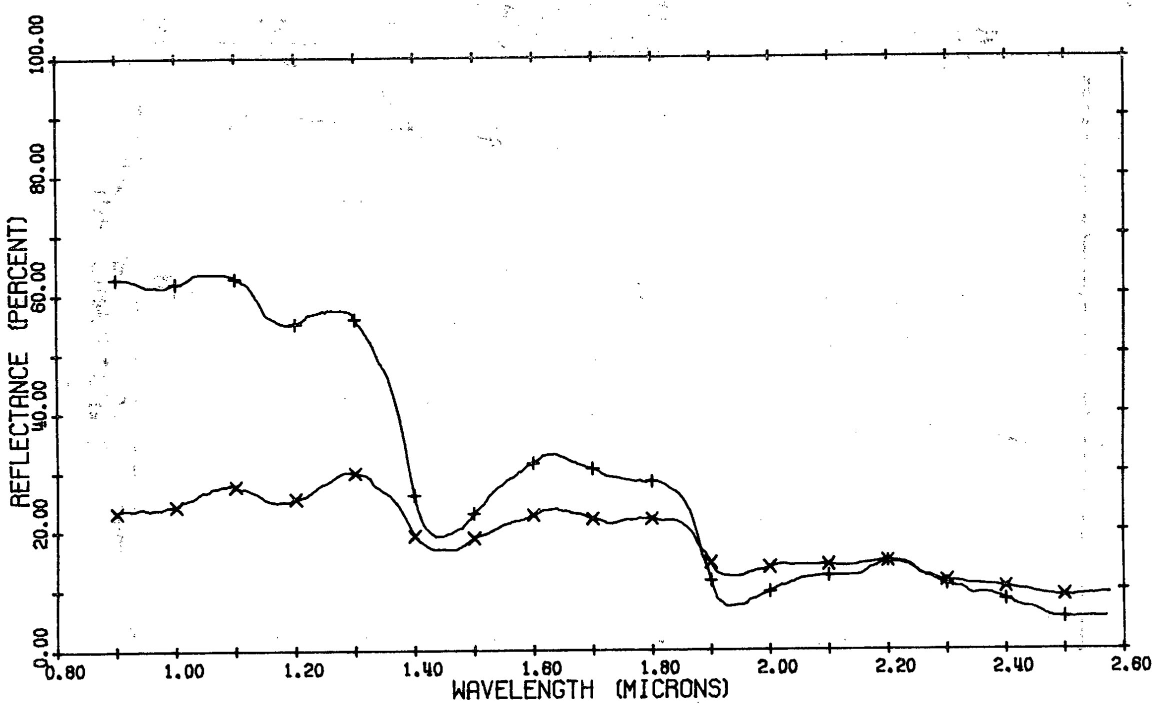

FIGURE 2-28. LABORATORY MEASUREMENTS, CREOSOTE.

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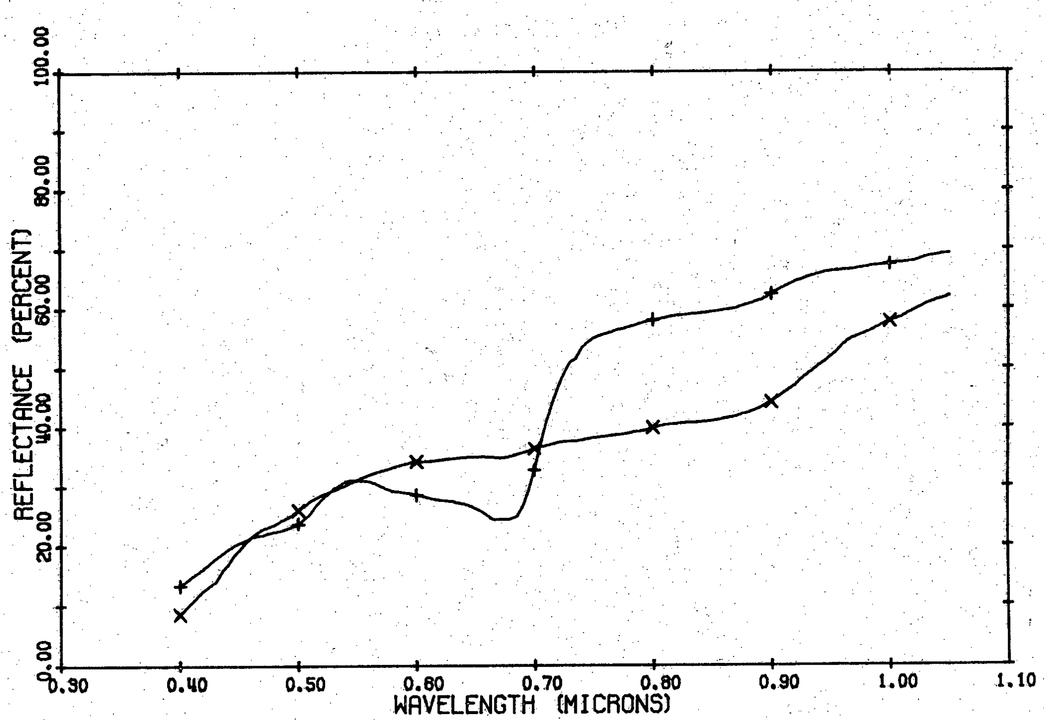

FIGURE 2-29. LABORATORY MEASUREMENTS, UNKNOWN.

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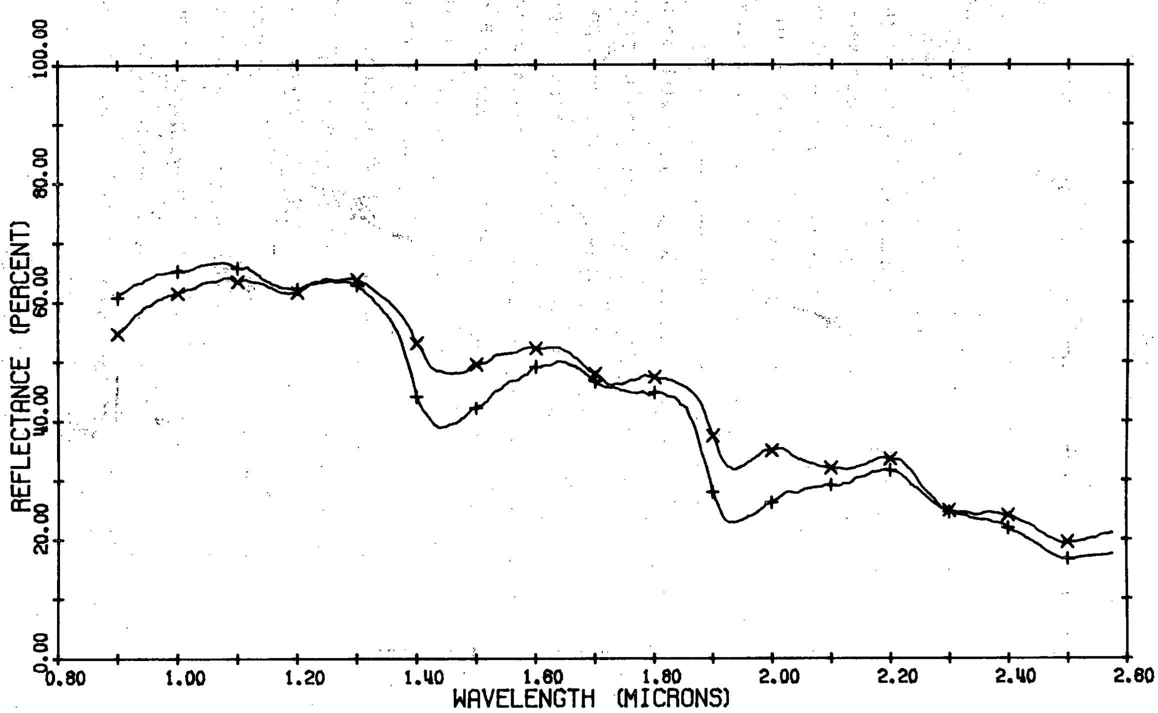

FIGURE 2-30. LABORATORY MEASUREMENTS, UNKNOWN.

3.0

FIELD MEASUREMENTS

3.1 INSTRUMENTATION

Field measurements were made of the spectral reflectance of various plants in the field with a modified Beckman Microspec infrared spectrophotometer.* As manufactured, the Microspec is a dual beam instrument designed to measure spectral transmittance from 2.5 to 14.5 μm. A nichrome wire is used as the source of IR radiation with a thermocouple detector. Monochromaticity is achieved with a three segment circular variable filter. The following modifications had been made to the instrument so that it could be used for field reflectance measurements. A circular variable filter with segments covering the spectral range 0.4 to 2.6 μm was installed to provide the required spectral coverage; a silicon detector was used to cover the spectral range from 0.45 to 1.1 μm; and the source was replaced by a pair of fiber optic bundles, one for the solar illumination reference beam and the other for the field reflected energy beam. All of the instrument optics are reflective except for the field lens, which was replaced, hence no difficulties were encountered in using the instrument for visible and near IR measurements. In the future, a laminated Si-Pbs detector might be used to extend the instrument's response further into the IR, and a Si detector with an enhanced blue response should be used to extend the spectral coverage down to 0.4 μm. The spectral resolution of the instrument is approximately 5% (e.g., 30 nm at 0.6 μm). Measurement repeatability varied between 1 and 2 percent of full scale. Reflectance measurement accuracy is estimated to be 2% for low reflectance surfaces and 5% for high reflectance surfaces.

* This instrument in its modified form was loaned to ERIM by Dr. Gene Safir, Michigan State University.

The ratio of energy collected by the two fiber optic bundles is recorded on chart paper which is advanced with the rotation of the circular variable filter. In the field, one fiber bundle, the reference channel, views a horizontal solar-illuminated Eastman $BaSO_4$ white reference panel. The other fiber bundle views the plant. A 100% reflectance level is recorded about every 20 minutes, after every 4 or 5 field scans, with both fiber optic bundles directed at the solar-illuminated Eastman $BaSO_4$ white reference. A 0% line is established by blocking the "sample" optical beam. A Dydimium filter with known wavelength absorptions is inserted into the sample beam from time to time to define and check the wavelength calibration. The instrument field-of-view is determined by the acceptance angle of the fiber optic bundle which is roughly Gaussian with 50% of the energy collected within a full 20 degree cone angle.

3.2 FIELD MEASUREMENT DATA SUMMARY

Field reflectance measurement data were collected in the vicinity of Tucson, Arizona, on May 11 and 12, 1977, with the modified Beckman Microspec. The instrument was mounted in a cherry picker which was positioned above the plants for data collection. Thirty-five reflectance spectra were obtained in the spectral range from 0.45 to 1.1 μm on 11 varieties of plants as well as several areas of bare ground. These data were reduced using the same procedures as used for the laboratory data and described in Section 2.2. Along with each reflectance measurement, other ancillary data were recorded and have been put on magnetic tape along with the measurement data. These ancillary data include the solar zenith angle $TS(\theta_s)$, the solar azimuth angle measured from north $PS(\phi_s)$, the zenith and azimuth angles of the radiance from the plant to the instrument $TR(\theta_r)$ and $PR(\phi_r)$, the distance from the instrument to the top of the plant canopy R, and the local time of the measurement T (see Figure 3-1).

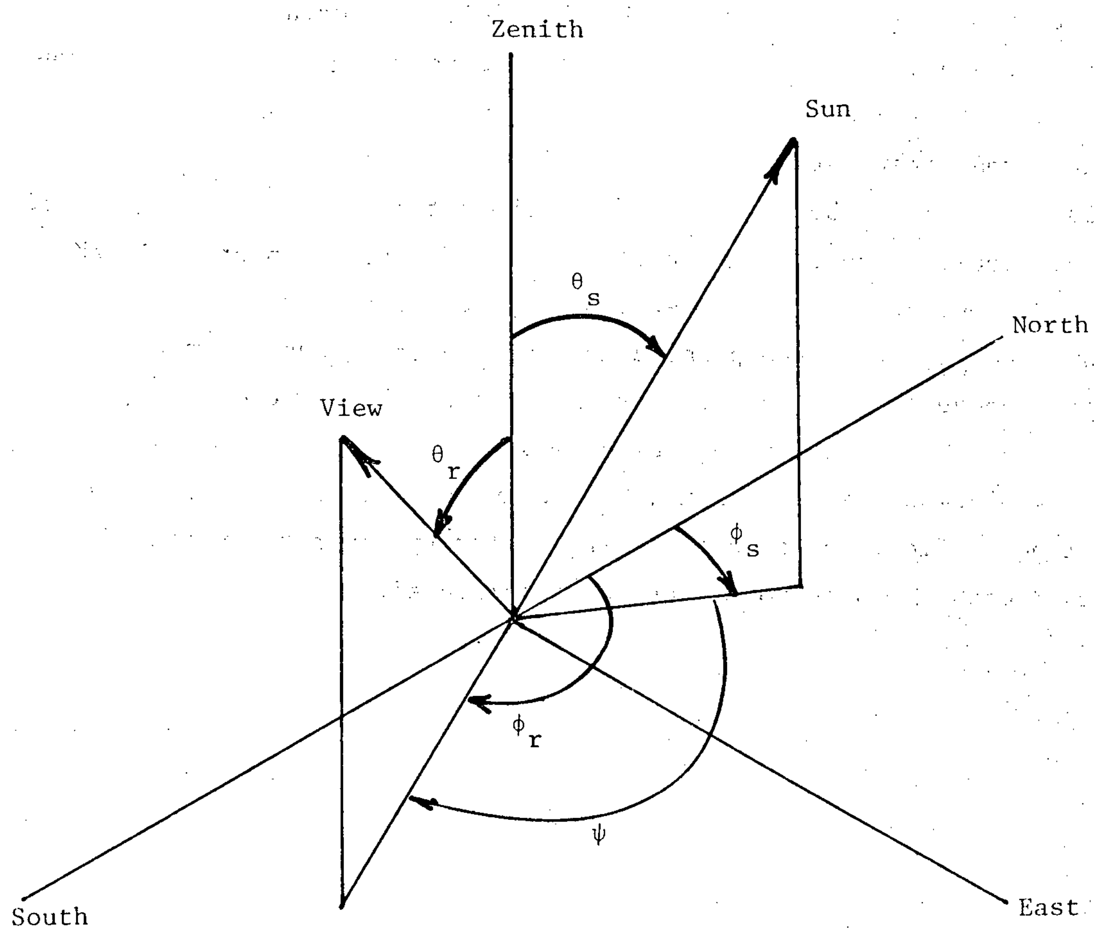

FIGURE 3-1. SUN POLAR ANGLES (θ_s, ϕ_s), VIEW POLAR ANGLES (θ_r, ϕ_r), AND RELATIVE AZIMUTH ANGLE ψ.

The description of all of the field measurement data obtained for this program is contained in Table 3-1. The data are presented in Figures 3-2 to 3-14. It is quite apparent from the field measurement data on jojobas and 10 other varieties of associated arid land plants that there are factors in addition to the leaf spectra as measured in the laboratory that contribute to the spectral signature. In particular, the much lower values of reflectance observed in the field can be attributed almost entirely to the fact that there are many shadows within the plant canopy and on the ground from the canopy above. From a cursory examination of these field data, it is also apparent that an unambiguous discrimination of jojoba spectra from creosote, dahlia, and the unidentified scrub spectra will be difficult because of their similarity under the range of conditions for which these data were collected.

TABLE 3-1 FIELD MEASUREMENT DATA SUMMARY

REFL											Figure Number
REFL		TUCSON, MALE JOJOBA									
CRUS	160208	JOJOBA 1, MALE	TR=20.	PR=245.	TS=34.	PS=109.	R=6.7	T=1005	(TUCSON)	5/12/77	3.2
X	160304	JOJOBA 2, MALE	TR=0.	PR=NA	TS=22.	PS=130.	R=5.5	T=1105	(TUCSON)	5/12/77	
SQUA	160306	JOJOBA 2, MALE	TR=0.	PR=NA	TS=19.	PS=132.	R=5.	T=1110	(TUCSON)	5/12/77	
DIAM	160404	JOJOBA 3, MALE	TR=0.	PR=NA	TS=15.	PS=197.	R=4.	T=1230	(TUCSON)	5/12/77	
O	160406	JOJOBA 3, MALE	TR=65.	PR=20.	TS=15.	PS=183.	R=7.	T=1215	(TUCSON)	5/12/77	
TRIA	160408	JOJOBA 3, MALE	TR=90.	PR=180.	TS=15.	PS=200.	R=8.	T=1235	(TUCSON)	5/12/77	
REFL		TUCSON, FEMALE JOJOBA									
CRUS	160308	JOJOBA 1, FEMALE	TR=50.	PR=270.	TS=18.	PS=137.	R=8.	T=1120	(TUCSON)	5/12/77	3.3
X	160508	JOJOBA 2, FEMALE	TR=40.	PR=200.	TS=21.	PS=230.	R=6.	T=1320	(TUCSON)	5/12/77	
SQUA	160704	JOJOBA 3, FEMALE	TR=10.	PR=0.	TS=40.	PS=258.	R=4.5	T=1455	(TUCSON)	5/12/77	
REFL		TUCSON, SOIL									
CRUS	160102	GROUND A	TR=30.	PR=225.	TS=43.	PS=98.	R=38IN	T=0910	(TUCSON)	5/12/77	3.4
X	160104	GROUND B	TR=30.	PR=135.	TS=44.	PS=97.	R=38IN	T=0905	(TUCSON)	5/12/77	
SQUA	160200	GROUND 1	TR=10.	PR=200.	TS=30.	PS=112.	R=12.	T=1015	(TUCSON)	5/12/77	
DIAM	160300	GROUND 2	TR=25.	PR=90.	TS=17.	PS=146.	R=7.	T=1135	(TUCSON)	5/12/77	
O	160402	GROUND 3, DARK	TR=30.	PR=90.	TS=15.	PS=186.	R=10.	T=1220	(TUCSON)	5/12/77	
TRIA	160500	GROUND 4	TR=30.	PR=225.	TS=23.	PS=235.	R=12.	T=1330	(TUCSON)	5/12/77	
REFL		TUCSON, CRESOTE									
CRUS	160802	CREOSOTE 2	TR=15.	PR=110.	TS=49.	PS=266.	R=2.	T=1540	(TUCSON)	5/12/77	3.5
X	160804	CREOSOTE 1	TR=20.	PR=200.	TS=46.	PS=263.	R=5.	T=1525	(TUCSON)	5/12/77	
REFL		TUCSON, DESERT BROOM									
CRUS	160706	DESERT BROOM 1	TR=40.	PR=45.	TS=40.	PS=259.	R=4.5	T=1500	(TUCSON)	5/12/77	3.6
X	160708	DESERT BROOM 1	TR=25.	PR=45.	TS=37.	PS=257.	R=3.5	T=1445	(TUCSON)	5/12/77	
REFL		TUCSON, ACACIA									
CRUS	160600	ACACIA 1	TR=15.	PR=160.	TS=28.	PS=246.	R=4.	T=1400	(TUCSON)	5/12/77	3.7
X	160602	ACACIA 1	TR=35.	PR=160.	TS=29.	PS=247.	R=5.	T=1405	(TUCSON)	5/12/77	

TABLE 3-1 (Concluded)

```
                                                                                  Figure
REFL                     TUCSON, UNIDENTIFIED SCRUB                               Number
CRUS   160106 SCRUB A, UNIDENTIFIED                          (TUCSON) 5/12/77
              MOSTLY CHLOROTIC LEAVES                                 5/12/77      3.8
              TR=30.  PR=225. TS=45.  PS=97.  R=20IN T=0900
X      160108 SCRUB B, UNIDENTIFIED                          (TUCSON) 5/12/77
              HALF CHLOROTIC LEAVES, HALF BRANCHES, LOTS OF GROUND SHADOW
              TR=20.  PR=270. TS=48.  PS=94.  R=24IN T=0845

REFL                     TUCSON, CHOLLA
CRUS   160504 CHOLLA 1                                       (TUCSON) 5/12/77
              DARK PLANT, SMALL YELLOW FLOWERS, NO BUDS               5/12/77      3.9
              TR=30.  PR=180. TS=22.  PS=233. R=12.  T=1325
X      160702 CHOLLA 2,                                      (TUCSON) 5/12/77

REFL                     TUCSON, PRICKLEY PEARS
CRUS   160502 PRICKLY PEAR                                   (TUCSON) 5/12/77
              TR=25.  PR=270. TS=24.  PS=237. R=4.   T=1305                        3.10

REFL                     TUCSON, SAGUARO
CRUS   160400 SAGUARO CACTUS        TOP                      (TUCSON) 5/12/77      3.11
              TR=10.  PR=90.  TS=14.  PS=180. R=1.   T=1210

REFL                     TUCSON, DAHLIA
CRUS   160206 DAHLIA 1                                       (TUCSON) 5/12/77
              TR=19.  PR=200. TS=33.  PS=108. R=6.5  T=1000                        3.12
X      160506 DAHLIA 2                                       (TUCSON) 5/12/77
              TR=28.  PR=160. TS=19.  PS=224. R=3.   T=1310

REFL                     TUCSON, PALO VERDE
CRUS   160202 PALO VERDE 1           MANY YELLOW FLOWERS     (TUCSON) 5/12/77
              TR=15.  PR=200. TS=28.  PS=116. R=7.5  T=1025                        3.13
X      160302 PALO VERDE 2           MANY YELLOW FLOWERS     (TUCSON) 5/12/77
              TR=45.  PR=245. TS=18.  PS=144. R=10.  T=1125

REFL                     TUCSON, MESQUITE
CRUS   160204 MESQUITE 1                                     (TUCSON) 5/12/77
              TR=8.   PR=160. TS=36.  PS=105. R=6.   T=0945                        3.14
X      160806 MESQUITE 2                                     (TUCSON) 5/12/77
              TR=15.  PR=180. TS=47.  PS=264. R=3.   T=1530
```

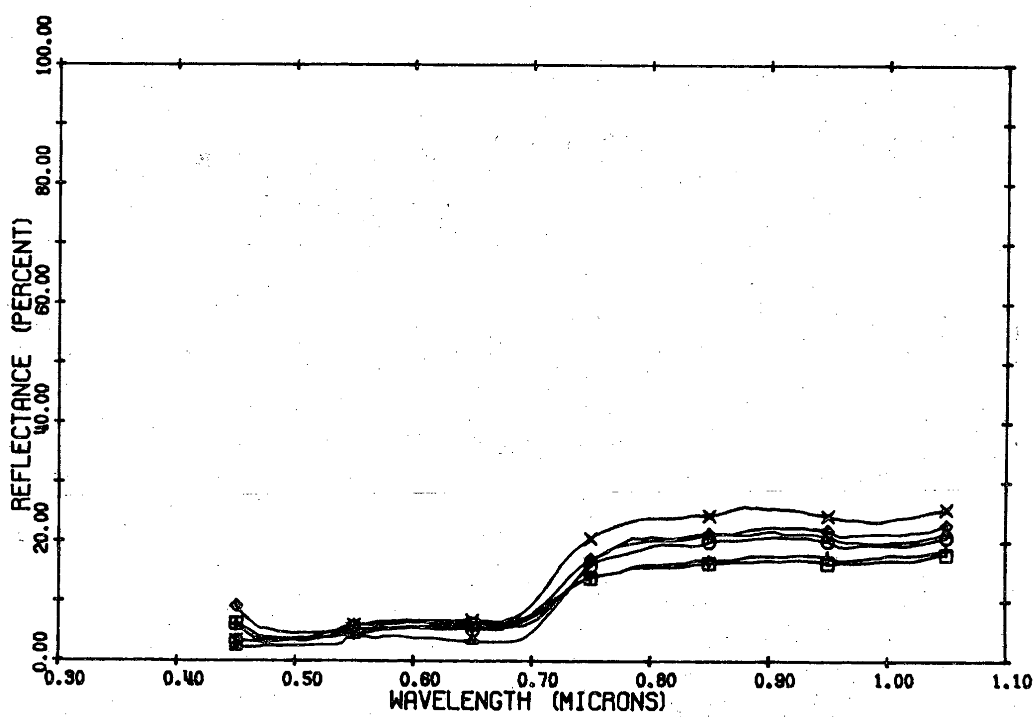

FIGURE 3-2. FIELD MEASUREMENTS, MALE JOJOBA LEAF

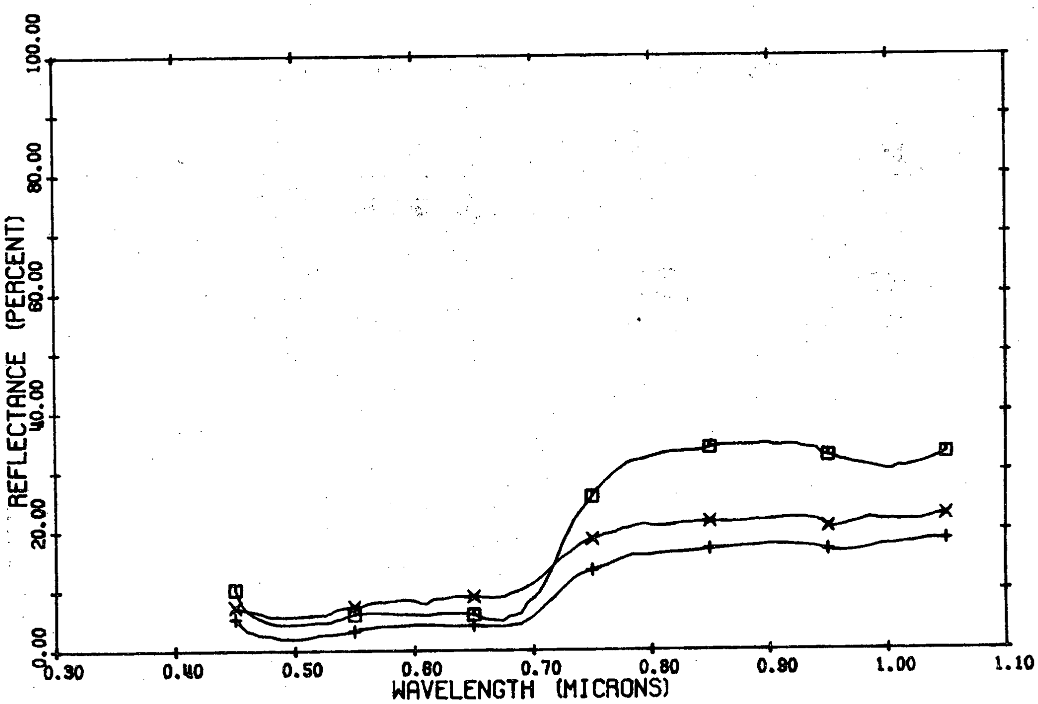

FIGURE 3-3. FIELD MEASUREMENTS, FEMALE JOJOBA LEAF.

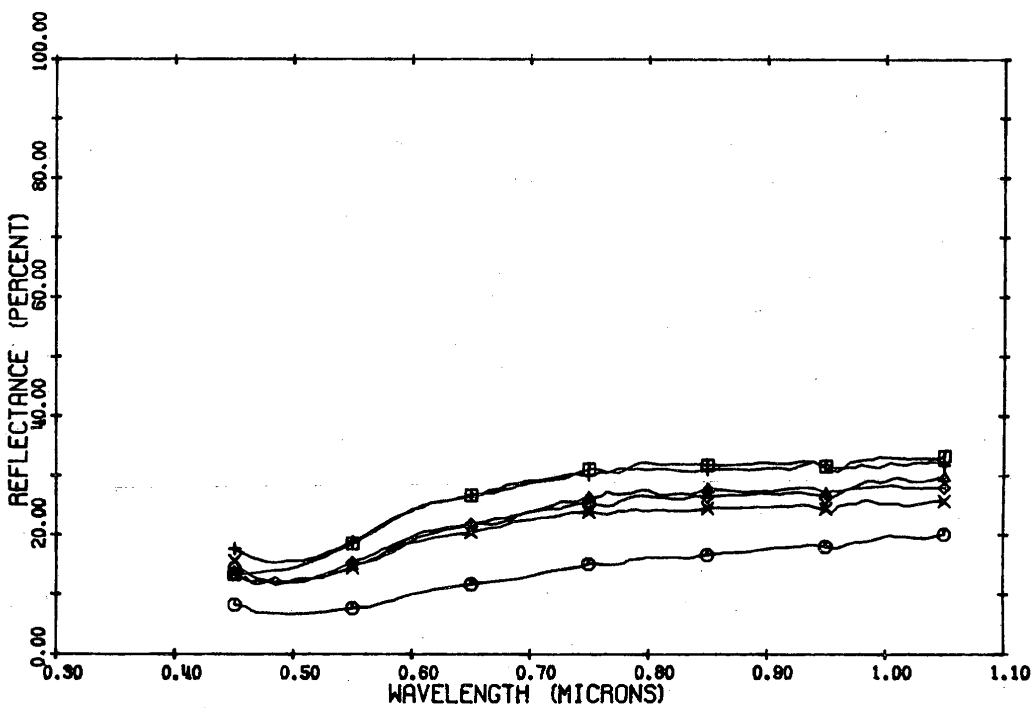

FIGURE 3-4. FIELD MEASUREMENTS, SOIL.

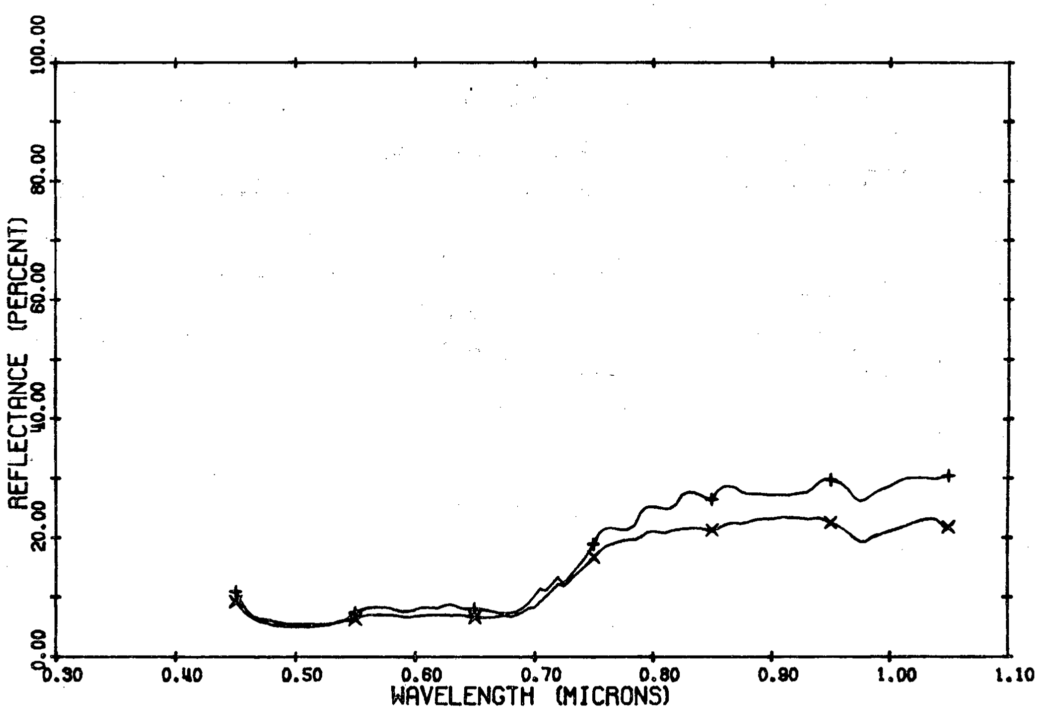

FIGURE 3-5. FIELD MEASUREMENTS, CREOSOTE.

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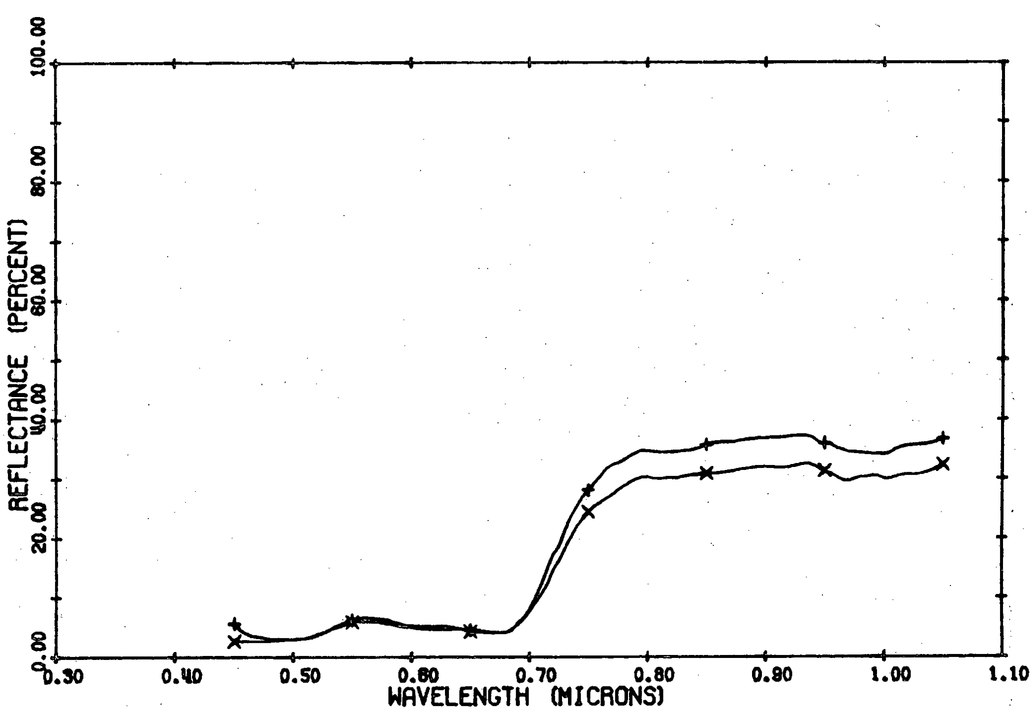

FIGURE 3-6. FIELD MEASUREMENTS, DESERT BROOM.

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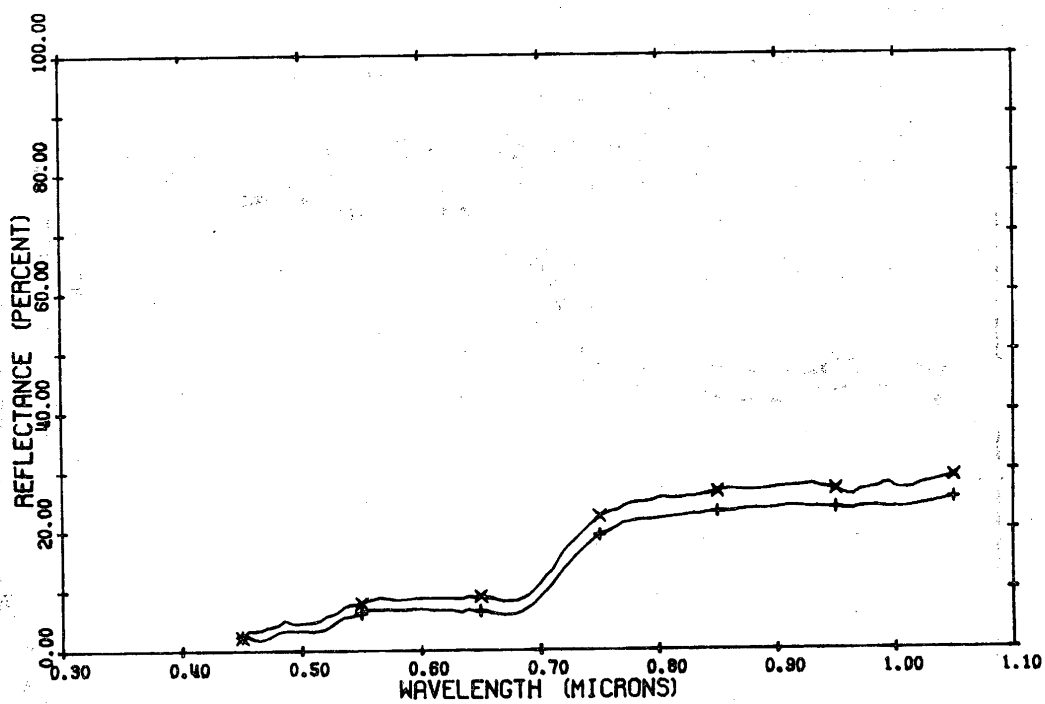

FIGURE 3-7. FIELD MEASUREMENTS, ACACIA.

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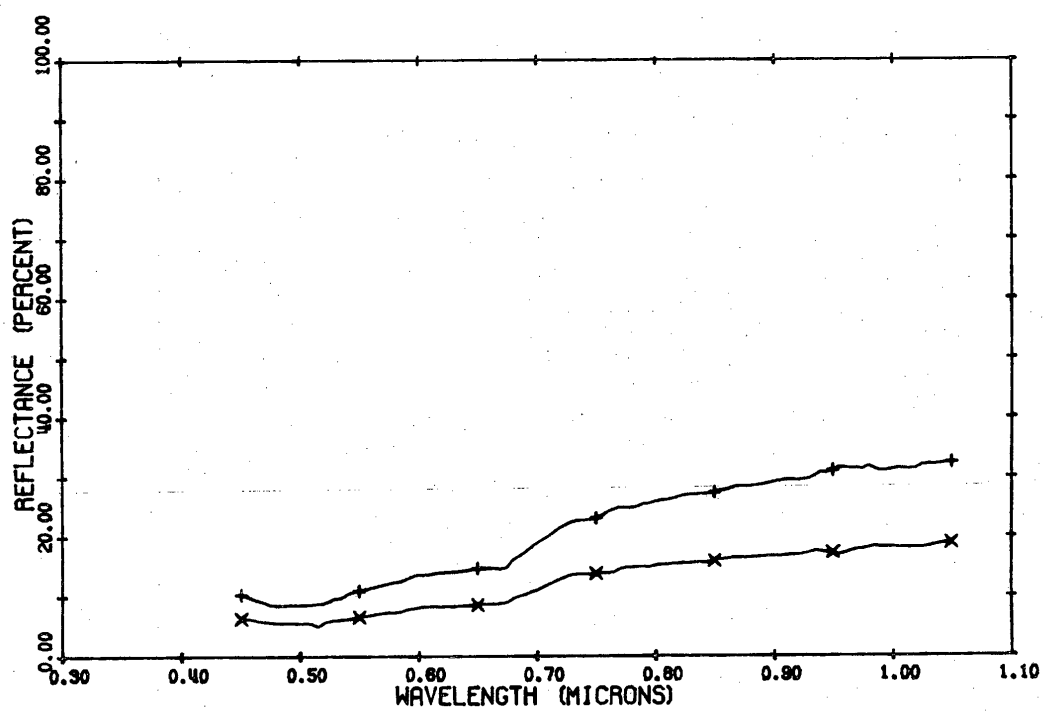

FIGURE 3-8. FIELD MEASUREMENTS, UNIDENTIFIED SCRUB.

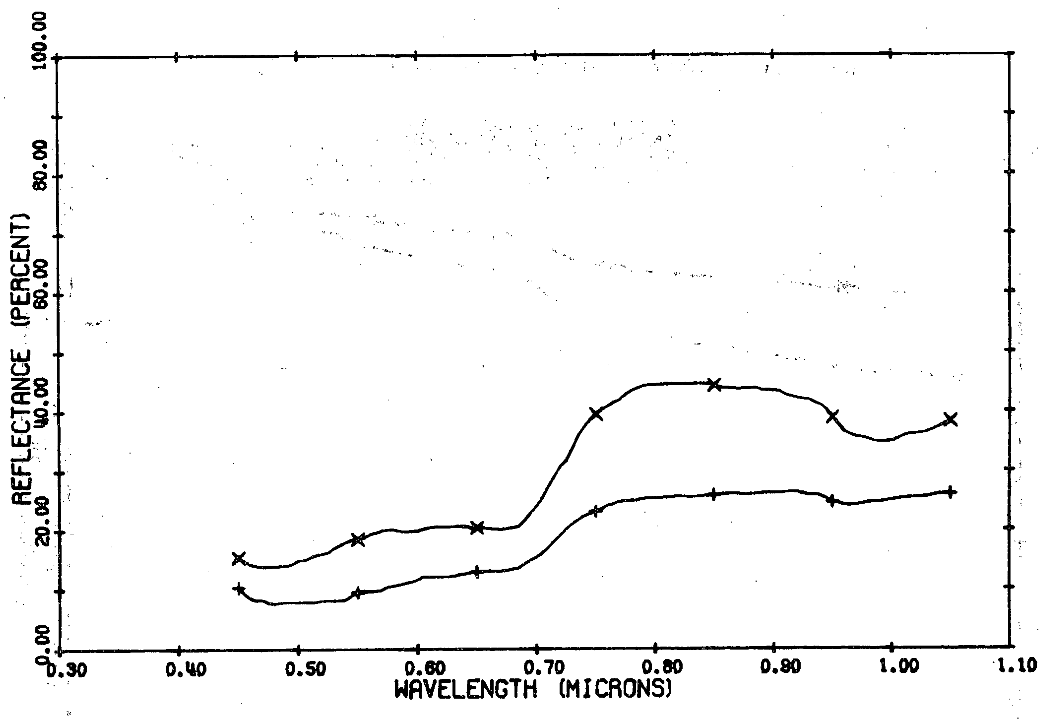

FIGURE 3-9. FIELD MEASUREMENTS, CHOLLA.

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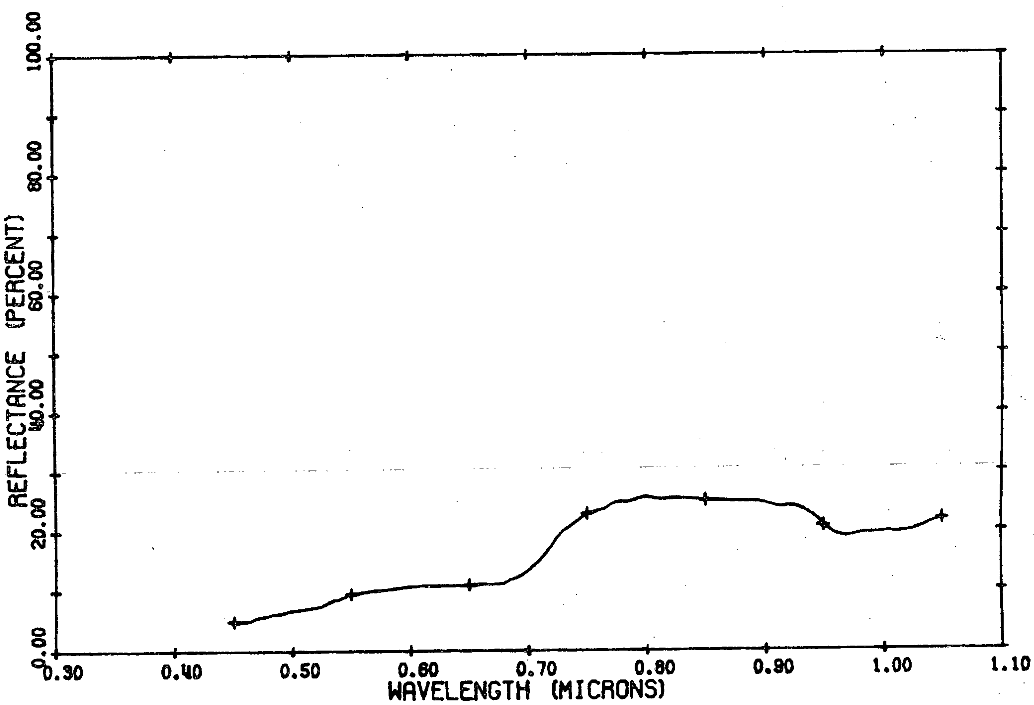

FIGURE 3-10. FIELD MEASUREMENTS, PRICKLY PEARS.

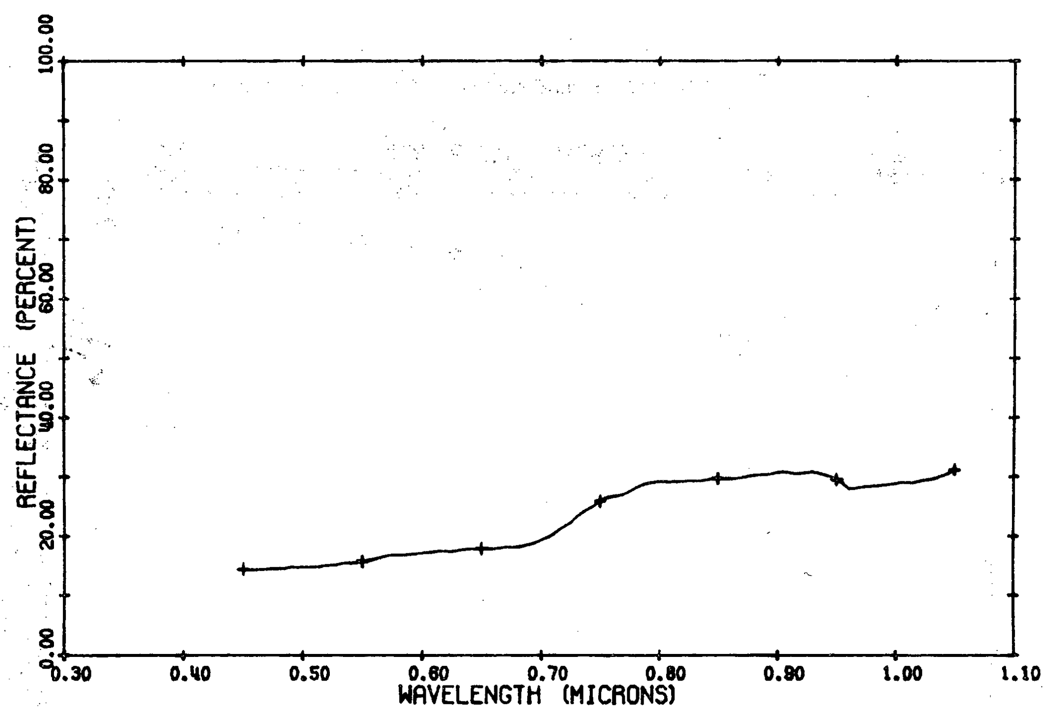

FIGURE 3-11. FIELD MEASUREMENTS, SAGUARO.

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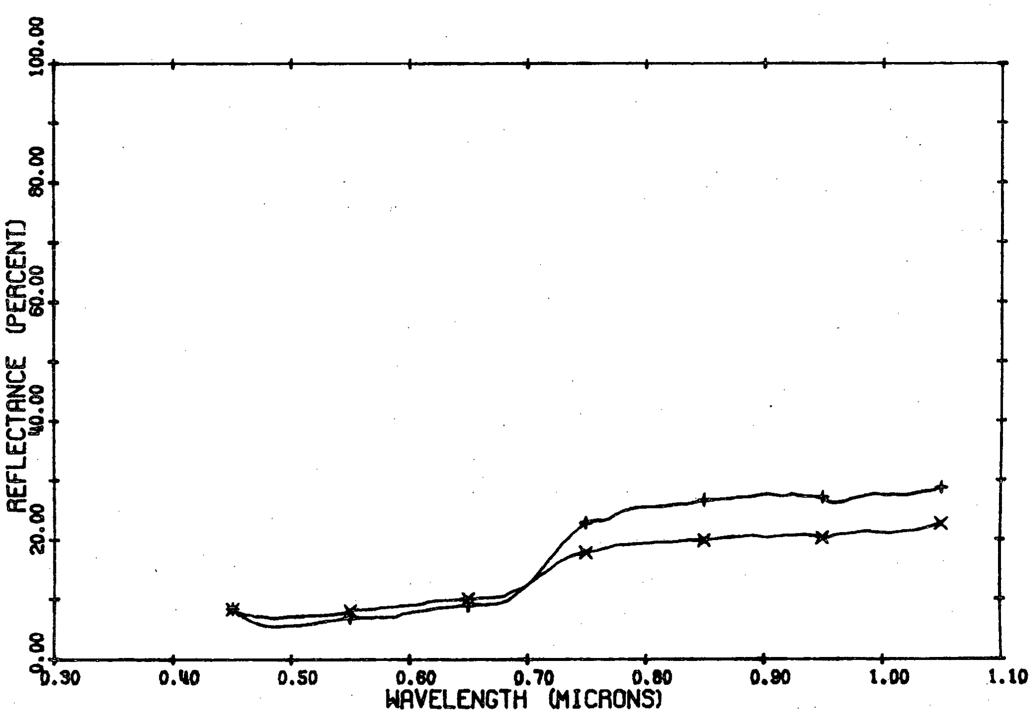

FIGURE 3-12. FIELD MEASUREMENTS, DAHLIA.

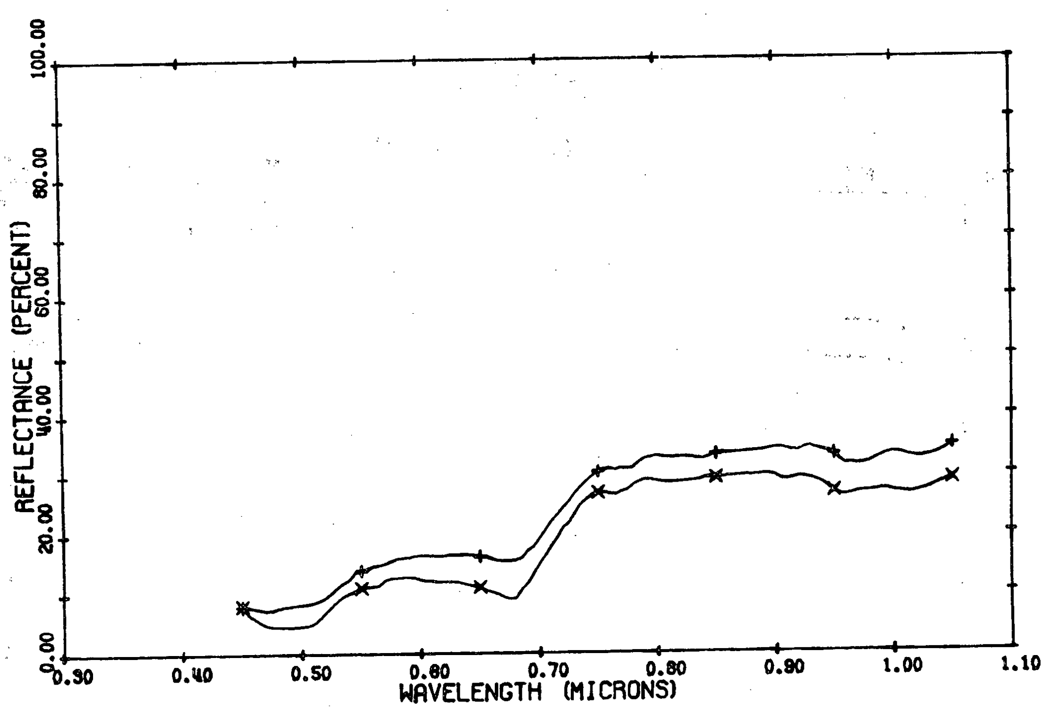

FIGURE 3-13. FIELD MEASUREMENTS, PALO VERDE.

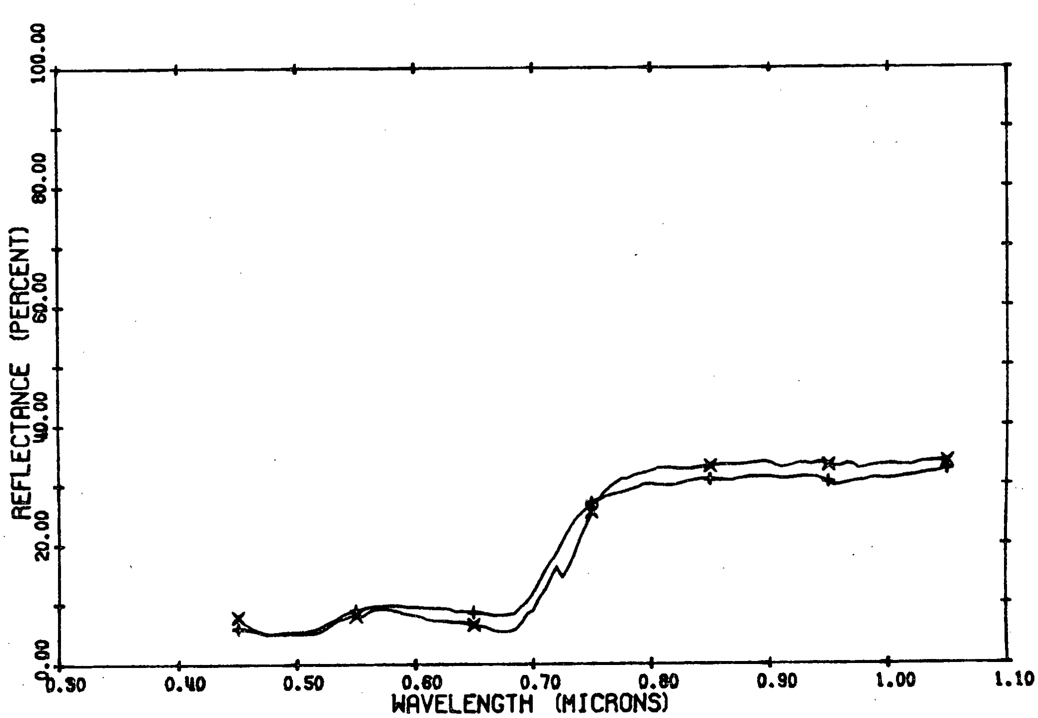

FIGURE 3-14. FIELD MEASUREMENTS, MESQUITE.

4.0

MULTISPECTRAL SIGNATURE ANALYSIS

The objective of this measurement and analyses program is to assess the potential for using multispectral remote sensing techniques to map the locations of jojoba plants over large areas of Arizona and New Mexico. The laboratory and field spectral reflectance measurements form the data base for the multispectral signature analyses task described in this section of the report.

There are very obvious and significant differences between the spectral reflectances of leaves as measured in the laboratory and the spectral reflectances of plants as measured in the field. In addition there is significant variability in the field measured reflectances from plant to plant and with sun and view angles. In order to assess the differences between the spectra of jojoba plants and the other associated plant types likely to be found in the same areas as jojobas, it is necessary to employ plant canopy reflectance modeling techniques to utilize and extrapolate the data base of limited measurement data to the wide range of conditions likely to be encountered under operational remote sensing conditions. The plant canopy reflectance model that has been utilized is described briefly in Section 4.1. The analysis techniques used to evaluate the potential for multispectral sensing to map jojobas are presented in Section 4.2. Results of the analysis are discussed in Section 4.3.

4.1 THE SUITS VEGETATIVE CANOPY MODEL

A plant canopy model has been developed by G. Suits, [References 2, 3, and 4], in which a plant or vegetative canopy is represented by a

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[2] Suits, G. H., The Calculation of the Directional Reflectance of a Vegetative Canopy, Remote Sensing of the Environment 2, p. 117 (1972).

[3] Suits, G. H., The Cause of Azimuthal Variations in Directional Reflectance, Remote Sensing of the Environment 2, p. 175 (1972).

[4] Suits, G. H., and Safir, G. R., Verification of a Reflectance Model for Mature Corn with Applications to Corn Blight Detection, Remote Sensing of the Environment 2, p. 183 (1972).

randomly distributed collection of horizontal and vertical plant components including leaves, stems, and as required flowers, buds, nuts, etc. A brief summary of the model formulation is given in Appendix A. The model is formulated along the lines of the familiar Kubelka-Munk equations, [Reference 5]. The reflectance of the canopy can be calculated for any sun angle θ_s, view angle θ_r, and relative azimuth angle $\psi = \phi_s - \phi_r$. Shadows and the diffuse flux produced by transmission through the leaves and multiple reflections, which cause the pronounced differences between laboratory and field measurement data, are included in the model.

The total horizontal leaf area per unit volume H, the total vertical leaf area per unit volume V, and the depth of the canopy d are the geometrical parameters which define the canopy. They are determined from photographs or actual physical measurements of the plants themselves. The laboratory measured spectral reflectance and transmittance properties of the leaves and of the soil understory are the optical inputs to the model.

Figures 4-1, 4-2, and 4-3 show the results of applying the model and calculating field reflectances using geometrical parameters estimated from photographs and leaf and bark spectral reflectances measured in the laboratory. The generally lower reflectances observed in the field relative to the spectral reflectances measured in the laboratory are correctly predicted by the model. Due to the limited extent of this analysis, the sources of variability observed in the field data have not been identified as to whether they are due to geometrical differences between individual plants or the differences in sun angle and view angle measurement conditions as predicted by the model. The specific parameters geometrical used to model the reflectances of the jojoba plant in Figure 4-1, 4-2, and 4-3 are given in Table 4-1.

[5] Kubelka, P. and Munk, F. Z., Tech. Physik 11, p. 593 (1931).

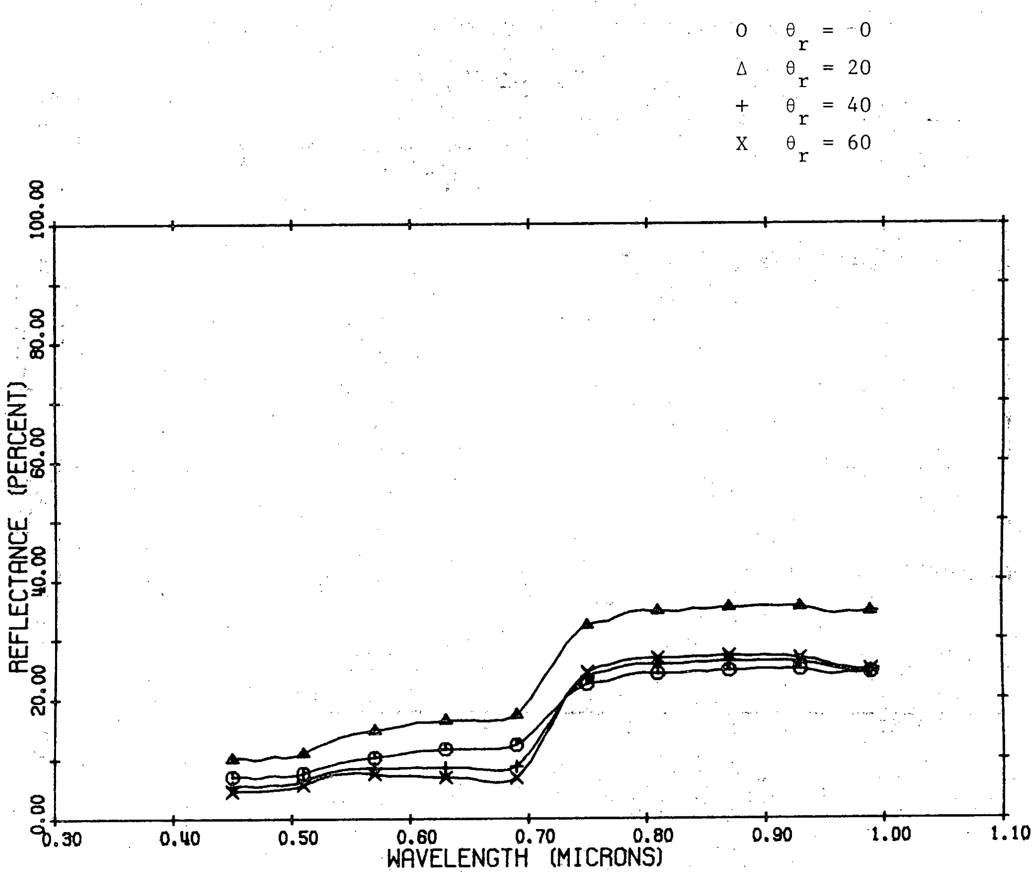

FIGURE 4-1. FIELD REFLECTANCE FOR JOJOBA PLANT CALCULATED USING THE SUITS CANOPY MODEL FOR SEVERAL VIEWER ANGLES θ_r WITH THE SUN ANLGE θ_s = 40° AND WITH THE RELATIVE AZIMUTH BETWEEN THE SUN AND VIEW ψ = 0°.

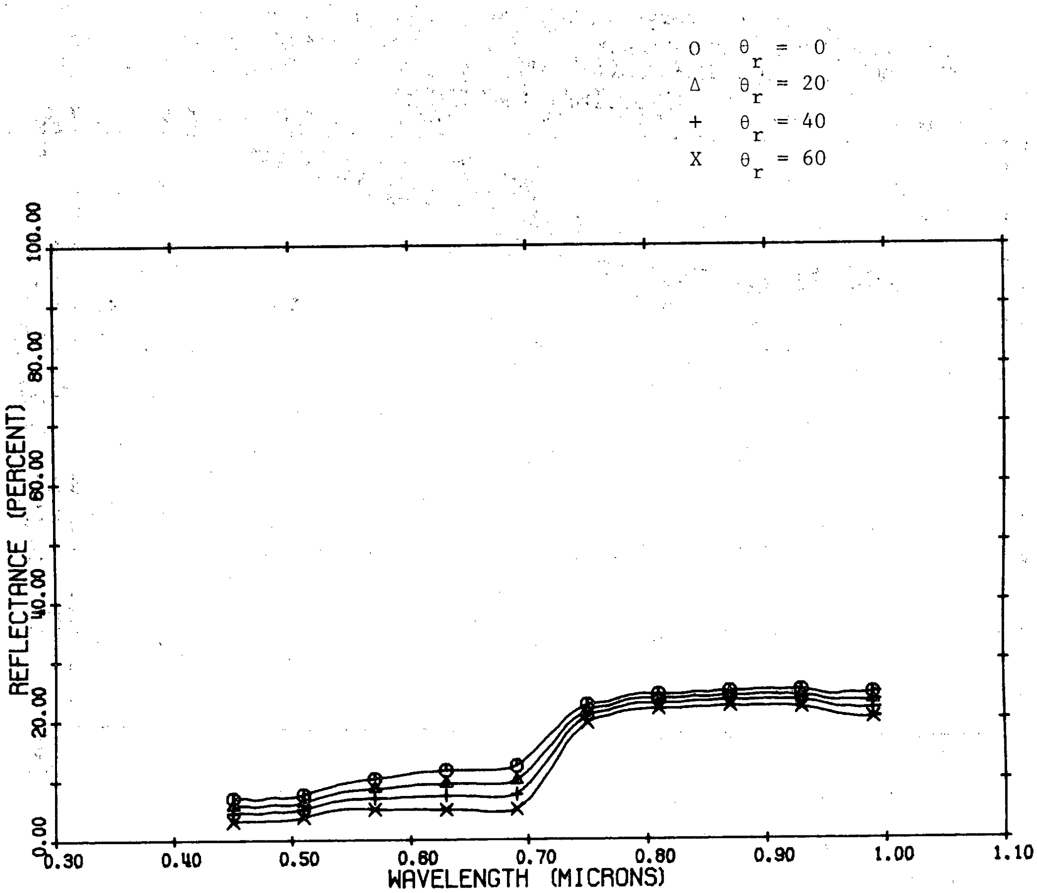

FIGURE 4-2. FIELD REFLECTANCE FOR JOJOBA PLANT CALCULATED USING THE SUITS CANOPY MODEL FOR SEVERAL VIEWER ANGLES θ_r WITH THE SUN ANGLE θ_s = 40° AND WITH THE RELATIVE AZIMUTH BETWEEN THE SUN AND VIEWER ψ = 90°.

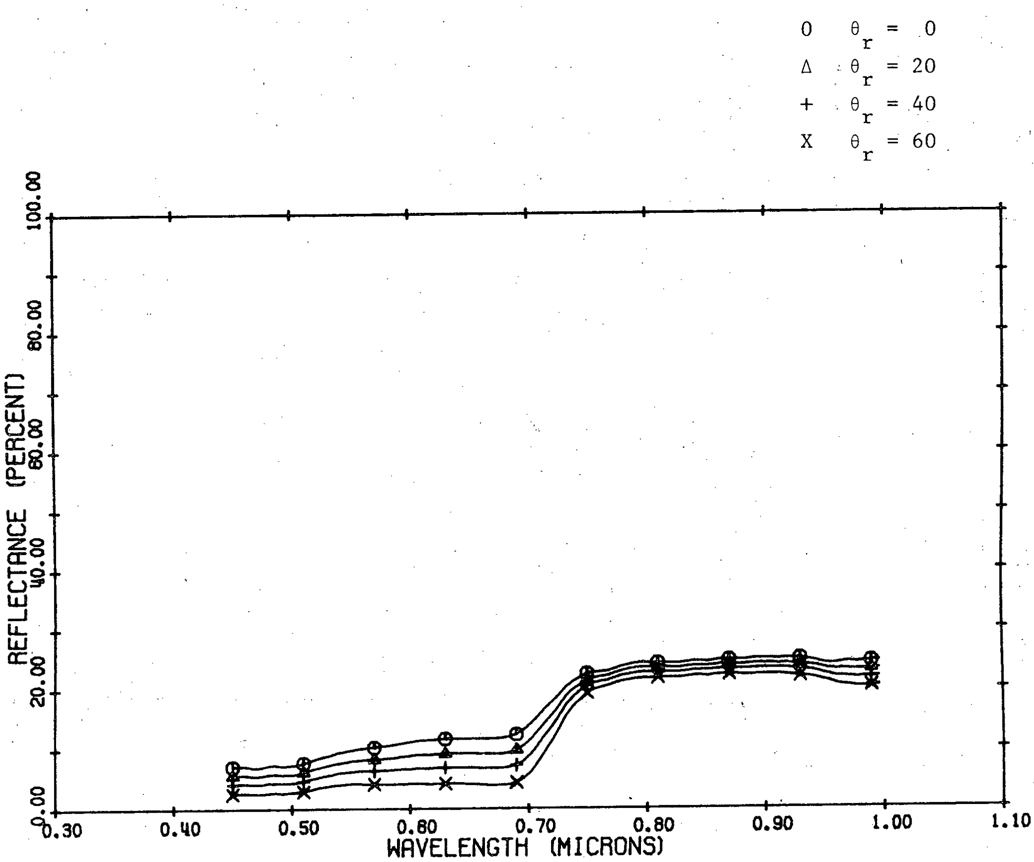

FIGURE 4-3. FIELD REFLECTANCE FOR JOJOBA PLANT CALCULATED USING THE SUITS CANOPY MODEL FOR SEVERAL VIEWER ANGLES θ_r WITH THE SUN ANGLE $\theta_s = 40°$ AND WITH THE RELATIVE AZIMUTH BETWEEN THE SUN AND VIEWER $\psi = 180°$.

TABLE 4-1

GEOMETRICAL PARAMETERS AND SPECTRA USED TO MODEL THE JOJOBA

	Top Layer	Lower Layer
Depth	X = -0.5 meter	X = -1.0 meter
Horizontal Leaf Area Index	H = 0.25 m^{-1}	H = 0.1 m^{-1}
Vertical Leaf Area Index	V = 2.0 m^{-1}	V = 0.2 m^{-1}
Horizontal Branches Area Index	H = 0.1 m^{-1}	H = 0.2 m^{-1}
Vertical Branches Area Index	V = 0.1 m^{-1}	V = 0.2 m^{-1}

Leaf Spectra:	Reflectance #61201, Table 3-1 Transmittance #61202, Table 3-1
Branches Spectra:	Reflectance #60602, Table 3-1
Soil Spectra:	Reflectance #160300, Table 3-1

4.2 MULTISPECTRAL ANALYSIS

The spectra of jojoba plants and associated arid land vegetation types under a wide variety of operational conditions are needed to assess the potential for multispectral remote sensing techniques to discriminate jojobas from other vegetation types to locate and map the jojoba population in the Southwest United States.

The field measurement data acquired on this program were used as the data base for this analysis, and the Suits canopy reflectance model was used to extrapolate these spectra to a wider variety of conditions than was actually measured on this program.

Although photographs were taken of all of the plants that were measured it was not possible within the scope of this program to model with laboratory spectra and measured geometrical characteristics each plant variety in detail and to verify the modeling. The approach that was taken instead was to use the Suits model to scale two field spectra obtained for each different variety of plant, where the measurement conditions for each variety were different, to a common range of operational conditions. In this way 54 spectra were generated from each field measured spectrum used in the analysis. All of the jojoba spectra were used in the analysis. The range of operational conditions for which simulated spectra were created are as follows:

<u>Jojobas*</u>

Sun Angle $\theta_s = 40°$
Viewer Angle $\theta_r = 0°$
Terrain Slope $\beta = 0°, 3°, 6°$
Azimuth of Terrain Slope Relative to Sun $\chi = 0°, 90°, 180°$
Variable Canopy Density V/H = 0.75, 1.0, 1.25
Number of Field Spectra Used, N = 9

* A wider range of terrain slopes for jojobas would be more typical of actual conditions. This would lead to an even larger number of false alarms than is produced with the range of terrain slopes used in the analysis.

Each Associated Vegetation Type and Light and Dark Soil

Sun Angle $\theta_s = 40°$

Viewer Angle $\theta_r = 0°$

Terrain Slope $\beta = 0°, 15°, 30°$

Azimuth of Terrain Slope Relative to Sun $\chi = 0°, 90°, 180°$

Variable Canopy Geometry V/H = 0.75, 1.0, 1.25

Number of Field Spectra Used, N = 2

The reflectance scaling used on each laboratory measured spectrum is derived directly from the Suits canopy model equations and is given by Equation 4-1 and derived in Appendix B.

$$\rho = \left[\rho(s) - \rho(u)(1 - C_o)^{1 + \eta_o}\right]\left[\frac{1 + \eta_o}{1 + \eta}\right] \times$$

$$\left[\frac{1 - (1 - C)^{1 + \eta}}{1 - (1 - C)^{1 + \eta_o}}\right] + \rho(u)(1 - C)^{1 + \eta} \qquad (4\text{-}1)$$

where C = Ground Cover

ρ = Model Reflectance

$\rho(s)$ = Field Measured Reflectance

$\rho(u)$ = Understory Field Measured Reflectance

$\eta = (\cos\theta + \delta\left(\frac{2}{\pi}\right)\sin\theta)/\cos\Theta$

θ = Sun Zenith Angle

Θ = Angle Between Sun's Ray and Normal-to-Ground Plane

δ = Ratio of Vertical Leaf Area Index to Horizontal Leaf Area Index

and where the subscript o denotes parameters associated with the actual field measurements.

The spectral signature of each variety of vegetation is characterized by 54 spectral radiances under 27 different sunlit conditions. Radiances were also calculated for shadowed plants. However, because of the low values of radiance under shadowed illumination sunlit and shadowed classes of each vegetation type were considered as separate classes for the analysis. For this analysis spectral radiances have been considered in four spectral bands.

Band 1	Blue	0.456 - 0.481 μm
Band 2	Green	0.531 - 0.556 μm
Band 3	Red	0.631 - 0.668 μm
Band 4	Near Infrared	0.806 - 0.893 μm

These bands were chosen so that the four major portions of the visible and near infrared spectrum would be sampled where there are likely to be differences amongst plant varieties. No attempt has been made to place these four spectral bands optimally or to determine the filter response functions optimally. It would not appear that overall multispectral sensor performance would be substantially improved with a slightly different choice of bands in the visible and near infrared. However, it is possible that inclusion of one or more spectral bands between 1.0 and 2.5 μm might improve performance because of the significant influence of water content in the plant on leaf reflectance in this part of the spectrum.

Probabilities of detection and false alarm for a four-band multispectral system are analyzed by considering each of the four-band spectra as a vector in a four-dimensional cartesian coordinate system. A "target" space is defined by a four-dimensional ellipse centered about the mean of all of the 243 sunlit jojoba spectra. Shadowed jojobas were not included with the sunlit jojobas in defining the target space because the radiances of all shadowed plants are low and very similar. It would be much more difficult to discriminate shadowed species from each other than it would be to discriminate sunlit species from each other. The principle axes of the ellipse are defined by the distribution of the target spectra about the mean. The size of the ellipse governs the probability of detection (the number of target spectra included in the ellipse) and the probability of false alarm (the number of background spectra included in the ellipse). The probability of false alarm from mixed background spectra is the fraction inside the ellipse of all of the points generated by taking linear combinations of all of the spectra from one background class with those of another.

Figure 4-4 shows the two dimensional projection of the sunlit jojoba ellipse onto the plane of the Channel 2 (Green, 0.531 - 0.566 μm) and Channel 3 (Red, 0.631 - 0.668 μm) plane. The ellipse contains 90% of the 243 jojoba spectra used for the analysis.

Figure 4-5 shows the projection of "background" ellipses that are defined in the same manner as the jojoba ellipse in Figure 4-4. It is clear that the radiances of the jojobas are, on the average, lower than the reflectances of some associated vegetation types in these two spectral bands. However, it is also clear that in these two bands the spectra of some of the backgrounds will be the same as the spectra of some of the backgrounds. This is in fact true for all pairs selected from the four spectral bands included in this analysis. Additional plots for other backgrounds and other spectral band pairs are included in Appendix B.

The results of the false alarm analysis, of counting the number of pure spectra and mixtures of spectra from different backgrounds are given in Table 4-3. The false alarm matrix in Table 4-3 is a false alarm matrix for a detection probability of 50%. Background classes in the false alarm matrix are numbered from 1 to 24, and they are identified in Table 4-2. There are five false alarm entries for each

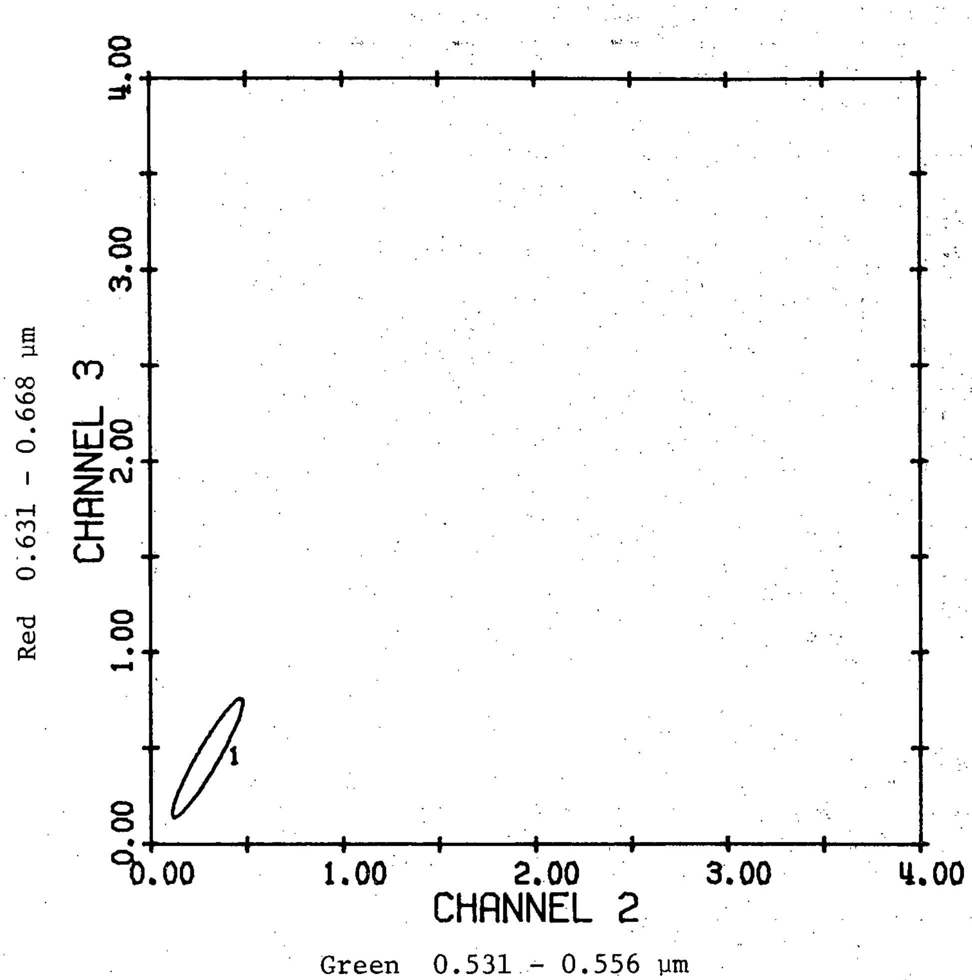

FIGURE 4-4. PROJECTION OF JOJOBA ELLIPSE ONTO THE GREEN - RED PLANE.

1 Sunlit Desert Broom
2 Sunlit Creosote
3 Sunlit Saguaro
4 Sunlit Prickly Pear
5 Sunlit Ground (Light)
6 Sunlit Ground (Dark)

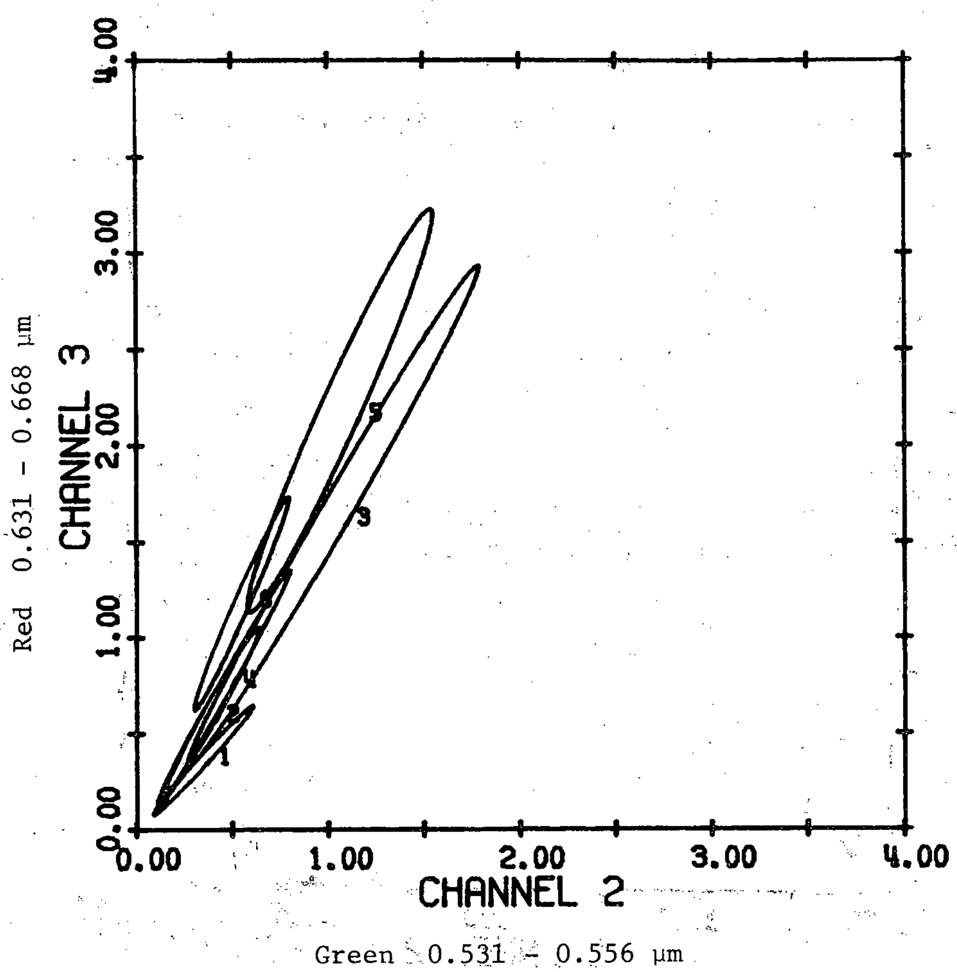

FIGURE 4-5. PROJECTION OF BACKGROUND ELLIPSES ONTO THE GREEN - RED PLANE.

mixture of background type M (a row in the table) and background type N (a column in the table). Each false alarm entry includes mixtures of 0, 20, 40, 60, 80 or 100% (a row index) of background type M with 100, 80, 60, 40, 20, and 0% of background type N. Each entry in the table is the percentage of spectra generated by taking the appropriate linear combinations of each of the 54 x 54 spectra of background that fall inside of the target ellipse. Diagonal elements in the matrix represent false alarms due to pure background spectra.

Examination of the false alarm matrix in Table 4-3 shows that false alarms are most likely to be produced by the sunlit spectra of the unidentified scrub, dahlia, and creosote. False alarms are also produced by the various mixed background spectra, for example, unidentified scrub and any of the other sunlit or shadowed backgrounds considered for this analysis. Hence, spectra from a variety of the associated arid land vegetation types will be incorrectly classified as jojoba spectra by a multispectral system with a threshold set for 50% probability of detection of true sunlit jojoba spectra.

False alarm matrices for a probability of detection threshold set at 10 and 90% are included in Appendix C. The false alarm rate at a detection probability of 90% is much higher. At a probability of detection of 10% all of the false alarms that arise from the spectra of pure vegetation types are eliminated, but false alarms from some mixed spectra remain.

Although a multispectra system might be useful in detecting 10% of the jojoba population, this analysis has shown the potential for serious false alarm problems from several background types. An analysis such as this generally underestimates false alarm rates because of the impracticability of calculating all of the sources of variability of radiance variation likely to be encountered in an

TABLE 4.2

BACKGROUND IDENTIFICATION NUMBERS
IN FALSE ALARM MATRICES

1	Sunlit Unidentified Scrub
2	Shadowed Unidentified Scrub
3	Sunlit Palo Verde
4	Shadowed Palo Verde
5	Sunlit Mesquite
6	Shadowed Mesquite
7	Sunlit Dahlia
8	Shadowed Dahlia
9	Sunlit Cholla
10	Shadowed Cholla
11	Sunlit Acacia
12	Shadowed Acacia
13	Sunlit Desert Broom
14	Shadowed Desert Broom
15	Sunlit Creosote
16	Shadowed Creosote
17	Sunlit Saguaro
18	Shadowed Saguaro
19	Sunlit Prickly Pear
20	Shadowed Prickly Pear
21	Sunlit Ground
22	Shadowed Ground
23	Sunlit Ground
24	Shadowed Ground

TABLE 4-3. PROBABILITY OF DETECTION SET AT 50 PERCENT

FALSE ALARM MATRIX 2 r = 3.36

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1 Scrub																								
0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	2.0	3.7	0.0	3.7	3.7	3.7	2.1	5.6	0.0	5.6	0.1	3.7	8.5	14.8	12.1	9.3	0.0	0.0	0.5	7.4	0.0	0.0	0.0	0.0
0.40	0.7	1.9	0.0	7.4	8.1	24.1	1.8	3.7	0.0	0.0	0.9	11.1	16.2	31.5	11.5	7.4	0.0	0.0	1.0	9.3	0.0	0.0	0.0	0.0
0.60	0.7	0.0	0.1	3.7	13.1	7.4	3.8	0.0	0.0	0.0	1.1	1.9	29.3	7.4	11.5	1.9	0.0	0.0	0.4	1.9	0.0	0.0	0.0	0.0
0.80	2.0	0.0	0.4	0.0	16.0	1.9	4.9	0.0	0.7	0.0	2.4	0.0	25.4	3.7	11.6	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0
1.00	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
2																								
0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0	27.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0	27.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 Palo Verde																								
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	0.0	5.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	22.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40			0.0	0.0	0.0	0.0	3.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4																								
0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	44.4	0.0	7.4	0.0	0.0	0.0	0.0	0.0	42.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 Mesquite																								
0.0					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	23.6	0.0	5.0	0.0	0.0	0.0	0.0	0.0	27.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40					0.0	0.0	21.7	0.0	4.7	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	1.9
0.60					0.0	0.0	13.5	0.0	5.5	0.0	0.0	0.0	0.0	0.0	8.7	0.0	0.0	0.0	0.0	0.0	0.2	0.0	2.9	0.0
0.80					0.0	0.0	3.7	0.0	3.6	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.1	0.0	0.0	0.0	2.5	0.0	5.2	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6																								
0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20						0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40						0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60						0.0	66.7	0.0	13.0	0.0	0.0	0.0	0.0	0.0	42.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80						0.0	9.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4-3 (Continued)

7 Dahlia																		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	2.5	0.0	0.0	0.0	0.2	0.0	9.1	1.9	9.3	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
0.40	4.5	27.8	0.2	25.9	6.6	53.7	19.9	66.7	11.2	35.2	0.0	1.9	9.8	51.9	0.0	1.9	0.0	11.1
0.60	4.5	27.8	0.2	25.9	9.3	42.6	30.4	42.6	8.2	29.6	0.0	14.8	10.0	38.9	0.0	16.7	0.0	18.5
0.80	2.5	3.7	9.7	3.7	15.0	5.6	24.5	9.3	3.4	3.7	0.1	1.9	11.4	5.6	0.0	3.7	0.0	3.7
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8																		
0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	3.7	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 Cholla																		
0.0			0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.3	0.0	6.0	3.7	6.5	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
0.40			0.0	0.0	1.9	7.4	7.8	9.3	2.4	3.7	0.0	0.0	0.9	7.4	0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.6	0.0	7.3	0.0	1.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
0.80			0.0	0.0	2.0	0.0	5.3	0.0	0.5	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10																		
0.0				0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	0.0	0.0	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 Acacia																		
0.0					0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	0.0	0.0	45.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40					0.0	0.0	0.0	0.0	32.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60					0.0	0.0	0.0	0.0	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80					0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12																		
0.0						0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20						0.0	0.0	0.0	20.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40						0.0	0.0	0.0	53.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60						0.0	0.0	0.0	42.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80						0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4-3 (Continued)

13 Desert Broom												
0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	24.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	3.7
0.40	0.0	0.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	5.6
0.60	0.0	0.0	12.8	0.0	0.2	0.0	0.0	0.0	1.2	0.0	11.8	0.0
0.80	0.0	0.0	5.5	0.0	2.4	0.0	0.0	0.0	5.1	0.0	12.7	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14												
0.0		0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	42.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	30.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 Creosote												
0.0			3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20			5.3	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0
0.40			5.5	5.6	0.0	0.0	22.6	29.6	0.0	5.6	0.0	5.6
0.60			5.5	14.8	0.0	0.0	44.7	35.2	0.0	14.8	0.1	14.8
0.80			5.3	11.1	0.5	5.6	39.3	14.8	0.8	9.3	1.7	9.3
1.00			3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
16												
0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 Saguaro												
0.0					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18												
0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80						0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4-3 (Concluded)

19	Prickly Pear						
0.0		0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0
20							
0.0			0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	0.0	0.0
0.40			0.0	0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0
21	Ground						
0.0				0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0
22							
0.0					0.0	0.0	0.0
0.20					0.0	0.0	0.0
0.40					0.0	0.0	0.0
0.60					0.0	0.0	0.0
0.80					0.0	0.0	0.0
1.00					0.0	0.0	0.0
23	Ground						
0.0						0.0	0.0
0.20						0.0	0.0
0.40						0.0	0.0
0.60						0.0	0.0
0.80						0.0	0.0
1.00						0.0	0.0
24							
0.0							0.0
0.20							0.0
0.40							0.0
0.60							0.0
0.80							0.0
1.00							0.0

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operational environment. For this reason and on the basis of this analysis, it is concluded that the spectral signature characteristics of jojobas are not sufficiently unique that jojobas can be located with a high probability of detection and low probability of false alarm just on the basis of spectral signature characteristics alone. A multispectral sensor might be of considerable use for surveying large areas of terrain and identifying just those areas for which detailed photointerpretation would be warranted in locating jojoba plants.

5.0

CONCLUSIONS AND RECOMMENDATIONS

The major objective of this program has been to analyze the spectral signatures of jojobas and associated arid land vegetation types to assess the potential for locating jojoba populations with a multispectral sensor. Laboratory and field spectral measurement data were collected in order to provide a data base for this analysis.

The field data show that the spectral reflectances for jojobas and several other plant types, especially creosote, dahlia and an unidentified scrub, are quite similar and generally lower than the spectral reflectances of other plant types. The Suits vegetative canopy model offers an insight to this phenomenon via the dependence of the field reflectance on both the laboratory measured spectral reflectance and transmittance and the geometrical characteristics of the plant. The cause for the low reflectances of the jojoba is the large amount of shadowing within the canopy and the depth of the shadows due to the low transmission of the leaves.

On the basis of the multispectral signature analysis conducted for this program it is clear that the multispectral signature characteristics of the jojoba are not sufficiently unique that jojobas can be located with a high probability of detection and a low false alarm rate solely on the basis of the spectral signature characteristics. The multispectral sensor would appear to offer the best potential as a screening sensor. As such the output of the multispectral sensor would be processed automatically and used to eliminate large areas with no jojobas, and photo interpretation of areas with jojobas and spectrally similar vegetative types would make the final discrimination. In order to more accurately assess the potential performance capability of multispectral sensing for such screening it would be necessary to collect and process some actual airborne multispectral scanner data over representative areas of interest and to obtain estimates for populations and associations of those plant types with spectra similar to jojobas.

Thus the potential roles of multispectral sensing and photographic sensing for locating and inventorying jojobas in a large area survey are identified as a result of this study.

- A multispectral scanner is potentially useful as a means for surveying large areas for the purpose of discriminating between those areas that may contain jojoba plants and those that do not. The multispectral scanner and processor will not be able to unambiguously discriminate jojoba plants from several other desert plants, but it may be a valuable way to eliminate very large areas that do not contain jojobas from a more detailed photographic survey. It is recommended that a limited multispectral scanner flight test program be conducted to evaluate the potential for using a multispectral scanner and processor to identify areas likely to contain jojobas and to discriminate against those large land areas that do not.

- Photographic interpretation will be necessary for the actual detection of jojoba plants. A possible photo-interpreter resource might be classes of high school students in those areas whose lands are being surveyed with instruction given as part of the classes.

6.0

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APPENDIX A

SUITS CANOPY MODEL

A.1 DERIVATION OF THE SUITS MODEL

The canopy model used for the calculations in Section 4 is the Suits model reported in Reference [2] with the alteration for azimuthal dependence prescribed in Reference [3].

The model starts with the differential equations for the radiant flow field

$$\begin{aligned} dE_\lambda(+d,i,x)/dx = &-a_i E_\lambda(+d,i,x) \\ &+ b_i E_\lambda(-d,i,x) \\ &+ c_i E_\lambda(s,i,x), \end{aligned} \tag{A-1}$$

$$\begin{aligned} dE_\lambda(-d,i,x)/dx = &\ a_i E_\lambda(-d,i,x) \\ &- b_i E_\lambda(+d,i,x) \\ &- c_i' E_\lambda(s,i,x), \end{aligned} \tag{A-2}$$

$$dE_\lambda(s,i,x)/dx = k_i E_\lambda(s,i,x) \tag{A-3}$$

Where $E_\lambda(\pm\, d,i,x)$ is the upward and downward diffuse flow of the i-th layer at level x and $E_\lambda(s,i,x)$ is the specular flux.

The constants a_i, b_i, c_i, c_i', and k_i are derived from measurements of canopy components of the i-th layer. If only one type of component occupies the i-th layer, then

$$a_i = [\sigma_h n_h (1 - \tau) + \sigma_v n_v (1 - \frac{\rho + \tau}{2})], \tag{A-4}$$

$$b_i = [\sigma_h n_h \rho + \sigma_v n_v (\rho/2 + \tau/2)], \tag{A-5}$$

$$c_i = [\sigma_h n_h \rho + (2/\pi)\sigma_v n_v (\rho/2 + \tau/2) \tan\theta], \tag{A-6}$$

$$c_i' = [\sigma_h n_h \tau + (2/\pi)\sigma_v n_v (\rho/2 + \tau/2) \tan\theta], \tag{A-7}$$

and

$$k_i = [\sigma_h n_h + (2/\pi)\sigma_v n_v \tan\theta] \qquad \text{(A-8)}$$

where σ_h is the average area of the projection of the canopy component on a horizontal plane, σ_v is the average area of the projection of the canopy component on two orthogonal vertical planes, n_h is the number of horizontal projections per unit volume, n_v is the number of vertical projections per unit volume, and the angle, θ (θ_s in Section 3) is the polar angle for incident specular flux.

The spectral transmittance, τ, and the spectral reflectance, ρ, are the hemispherical reflectance values obtained from measurements of component samples in the laboratory.

Up to four components were used, so the values a_i, b_i, c_i, c_i', and k_i are obtained separately for each component and then added to get a total value for the layer.

What is found is

$$\frac{\pi L_\lambda}{E_\lambda(s,0)} = R\ (\text{layer } 1) + R(\text{layer } 2) + R(\text{soil}) \qquad \text{(A-9)}$$

where L_λ is the radiance of the canopy and $E_\lambda(s,0)$ is the flux incident on the top of the canopy. The corrected relations for the R values are as follows:

$$\begin{aligned} R(\text{layer } 1) = {} & A_1[u_1\ (1 - f_1) + v_1(1 + f_1)] \\ & \times \{1 - \exp\ [x_1(K_1 + g_1)]\}/(K_1 + g_1) \\ & + B_1[u_1(1 + f_1) + v_1(1 - f_1)] \qquad \text{(A-10)} \\ & \times \{1 - \exp\ [x_1(K_1 - g_1)]\}/(K_1 - g_1) \\ & + [u_1 C_1 + v_1 D_1 + w_1] \\ & \times \{1 = \exp\ [x_1(K_1 + k_1)]\}/(K_1 + k_1) \end{aligned}$$

$$
\begin{aligned}
R(\text{layer } 2) = \exp\,[x_1(K_1 - K_2)]\Big\{ & A_2[u_2\,(1 - f_2) + v_2\,(1 + f_2)] \\
& \times \frac{\{\exp\,[x_1(K_2 + g_2)] - \exp\,[x_2(K_2 + g_2)]\}}{(K_2 + g_2)} \\
& + B_2\,[u_2(1 + f_2) + v_2(1 - f_2)] \\
& \times \frac{\{\exp\,[x_1(K_2 - g_2)] - \exp\,[x_2(K_2 - g_2)]\}}{(K_2 + g_2)} \\
& + [u_2C_2 + v_2D_2 + w_2 \exp\,[(k_1 - k_2)x_1]] \\
& \times \frac{\{\exp\,[x_1(K_2 + k_2)] - \exp\,[x_2(K_2 + k_2)]\}}{(K_2 + k_2)}\Big\}
\end{aligned}
\qquad \text{(A-11)}
$$

$$
\begin{aligned}
R(\text{soil}) = \exp\,[K_1x_1 + K_2(x_2 - x_1)] \times \{ & A_2(1 - f_2)\exp\,[g_2x_2] \\
& + B_2(1 + f_2)\exp\,[-g_2x_2] + C_2\exp\,[K_2x_2]\}
\end{aligned}
\qquad \text{(A-12)}
$$

A_i and B_i have been determined from the boundary conditions imposed on the solutions of Equations A-1 to A-3, namely that the upward and downward directed flux is continuous across the boundary layers, and that the downward directed flux at the soil level is reflected to produce the upward directed diffuse flux, and

$$
\begin{aligned}
C_i &= \frac{c_i(k_i - a_i) - c_i'b_i}{k_i^2 - g_i^2}\,E_\lambda(s, i - 1, x_{i-1}), \\
D_i &= \frac{-c_i'(k_i + a_i) - c_ib_i}{k_i^2 - g_i^2}\,E_\lambda(s, i - 1, x_{i-1}), \\
g_i &= (a_i^2 - b_i^2)^{1/2}, \text{ and} \\
f_i &= [(a_i - b_i)/(a_i + b_i)]^{1/2}
\end{aligned}
\qquad \text{(A-13)}
$$

The quantity $E_\lambda(s,i-1,x_{i-1})$ is the value of the specular irradiance at the bottom of the (i - 1)th layer, $x = x_{i-1}$.

$$u = \sigma_h n_h \tau + \sigma_v n_v \frac{\tau + \rho}{2} (2/\pi) \tan \phi,$$

$$v = \sigma_h n_h \rho + \sigma_v n_v \frac{\tau + \rho}{2} (2/\pi) \tan \phi,$$

$$\begin{aligned} w = {} & \sigma_h n_h \rho + \sigma_v n_v \tan \phi \tan \theta \\ & \times \left[\left(\frac{\rho}{2}\right) (\sin \psi + (\pi - \psi) \cos \psi)/\pi \right. \\ & \left. + \left(\frac{\tau}{2}\right) (\sin \psi - \psi \cos \psi)/\pi\right] \end{aligned} \tag{A-14}$$

ψ is the azimuthal angle between the sun and view positions, θ(θ_s in Section 3) is the sun polar angle, and ϕ(θ_r in Section 3) is the view polar angle. The distance from the top of the canopy to the bottom of layers 1 and 2 respectively are x_1 and x_2 which are defined such that $x_2 \le x_1 \le 0$.

The inputs to the model are then the transmittances and reflectances of the various components, $\sigma_h n_h$ and $\sigma_v n_v$ values for each component in each layer, the depth of the layers, and the sun and view positions.

The specific form of these inputs in this case utilized the definition

$$\begin{aligned} H_i &= \sigma_{h_i} n_{h_i} \\ V_i &= \sigma_{v_i} n_{v_i} \end{aligned} \tag{A-15}$$

where H_i and V_i have units of inverse length.

APPENDIX B
CALCULATION OF RADIANCES FOR A VARIETY OF CONDITIONS

B-1 DERIVATION OF EQUATION 4-1

An attempt has been made to simulate a multitude of field data for a variety of field conditions from a few spectra provided using the modified Suits model. The general form of the Suits model has been detailed in Appendix A. A brief discussion of the derivation of equation 4-1 is presented in this appendix. Because of limited information about the plants for which measurement data are available only single scattering is considered. This approximation can be expected to be best in the green where the leaf and understory reflectance is low. This is the best assumption that can be made without extensive knowledge of the geometric properties of the plants involved.

The starting point is Equation 23 in Reference [2].

$$\rho = \frac{\pi L_\lambda}{E_\lambda} \simeq w_1\ [1 - \exp\ (x(k + K))]/(K + k) + w_2 \exp\ (x(k + K)) \qquad \text{(B-1)}$$

where

ρ = canopy model reflectance

L_λ = radiance reflected by the canopy

E_λ = the irradiance of sunlight

w_1 = the leaf reflectance

w_2 = the understory reflectance

x = the canopy height from the top of the canopy $(x < 0)$

$K = (\sigma_h n_h \cos\phi + (\frac{2}{\pi})\sigma_v n_v \sin\phi)/\ CSL_\phi$

$$k = (\sigma_h n_h \cos\theta + (\frac{2}{\pi})\sigma_v n_v \sin\theta)/CSL_\theta$$

with

σ_h = horizontal leaf projection of a leaf per unit volume
σ_v = vertical leaf projection of a leaf per unit volume
n_h = number of horizontal leaves per unit volume
n_v = number of vertical leaves per unit volume
ϕ = view angle from nadir (θ_r in Section 3)
θ = sun angle from nadir (θ_s in Section 3)
CSL = stands for cosine of the angle between the normal to the ground and the sun or view positions.

It is assumed that the view is straight down, $\phi = 0°$. The slope of the ground is 0°, $CSL_\phi = 1$, for the field measurement.

Now let $H = \sigma_h n_h$ be the horizontal leaf area index, $V = \sigma_v n_v$ be the vertical leaf area index, and $\eta = (\cos\theta + \delta\ (2/\pi)\sin\theta)/CSL$ where $\delta = V/H$, the ratio of the vertical to the horizontal leaf area indices. Let $|x| = 1$ unit of length.

With this notation we have

$$\rho = \frac{\pi L_\lambda}{E_\lambda} = w_1[1 - \exp(-H(1+\eta))]/(H(1+\eta)) + w_2 \exp(-H(1+\eta)) \quad \text{(B-2)}$$

so, with the definition $C = 1 - \exp(-H)$,

$$\rho = \frac{\pi L_\lambda}{E\lambda} = \frac{w_1}{H}\left[1 - (1-C)^{(1+\eta)}\right]/(1+\eta) + w_2(1-C)^{(1+\eta)} \quad \text{(B-3)}$$

Hence, the reflectance measured in the field, $\rho(s)$, is given by

$$\rho(s) = \frac{\pi L_\lambda}{E_\lambda} = \frac{w_1}{H_o}\left(1 - (1 - C_o)^{(1 + \eta_o)}\right)\Big/(1 + \eta_o) + W_2(1 - C_o)^{(1 + \eta_o)} \qquad \text{(B-4)}$$

where the subscript denotes values measured in the field. Thus, combining B-3 and B-4, the general canopy model reflectance becomes

$$\rho = \frac{\pi L_\lambda}{E_\lambda} = \left[\rho(s) - w_2(1 - C_o)^{(1 + \eta_o)}\right]\frac{(1 + \eta_o)}{(1 + \eta)}\frac{\left(1 - (1 - C)^{(1 + \eta)}\right)}{\left(1 - (1 - C_o)^{(1 + \eta_o)}\right)}$$

$$+ w_2(1 - C)^{(1 + \eta)} \qquad \text{(B-5)}$$

which is Equation 4-1 recognizing that $w_2 = \rho(u)$.

If one includes sunlight and skylight contributions, the total expression is:

$$\pi L_\lambda = E_\lambda(\text{sun}) * CSL_\theta * \left\{\left[\rho(s) - \rho(u)(1 - C_o)^{(1 + \eta_o)}\right]\right.$$

$$\left. * \frac{\left[1 - (1 - C)^{(1 + \eta)}\right]}{\left[1 - (1 - C_o)^{(1 + \eta_o)}\right]} * \frac{1 - \eta_o}{1 + \eta} + \rho(u) * (1 - C)^{(1 + \eta)}\right\}$$

$$\text{(B-6)}$$

$$+ E_\lambda(\text{sky}) * \left\{\left[\rho(s) - (1 - C_o)^{(1 + \eta_o)}\right]\right.$$

$$\left. * \frac{[1 - (1 - C)^3]}{\left[1 - (1 - C_o)^{(1 + \eta_o)}\right]} + \rho(u) * (1 - C)^3\right\}$$

where a specific η has been chosen to represent the skylight contributions.

B-2 CALCULATION OF RADIANCES

The values of E_λ (sun) and E_λ (sky) are obtained both from published literature and from experiment. The spectral irradiance of direct sunlight is taken from the curves of P. Moon [Reference 6] for air mass = 2 shown in Figure B-1. The change in magnitude is obtained using the variation of solar illuminance with sun angle given in the RCA Electro-optics Handbook [Reference 7]. The sky spectral irradiance is obtained for clear days using unpublished experimental data of G. Suits indicating that the ratio of sky to total irradiance is

$$E_\lambda(\text{sky})/[E_\lambda(\text{sun})\cos\theta + E_\lambda(\text{sky})] = A(\lambda/600)^{-2.5}$$

where

$$A = E_v(\text{sky})/2[E_v(\text{sun})\cos\theta + E_v(\text{sky})]$$

$$\lambda = \text{wavelength in nm.}$$

E_v (sky) was taken from an ITEK publication. The ratio $\dfrac{E_\lambda\ (\text{sky})}{[E_\lambda\ (\text{sun})\cos\theta + E_\lambda\ (\text{sky})]}$ is shown in Figure B-2. Band radiances $L_i = \int f_{\lambda_i} L_\lambda d\lambda$ are calculated numerically for four wavelength bands (channels) assuming the detectors have a square filter response. In an effort to better simulate actual field conditions, a random error of between $\pm 3\%$ was added to each channel. Both sunlit and shadowed backgrounds were generated. For shadowed, only the skylit portion of Equation B-6 is used.

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[6] Moon, P., J. Franklin Institute, 230, 583 (1940).

[7] Electro-Optics Handbook Technical Series EOH-11, RCA Corporation, Commercial Engineering, Harrison, N. J., August 1974.

The results of these band radiance calculations are used in the detection simulation presented in Section 4 and Appendix C. The results are shown graphically in Figures B-3 to B-5 where each ellipse corresponds to the projection of a 4-dimensional ellipsoid which contains 90% of the 54 4-space vectors, generated using the parameters in Section 4 for a particular species, on the two-dimensional plane defined by the axes. The ellipses for the jojoba signature are the decision boundaries for a conditional P_D of 0.9 while the ellipses for the background species serve only to illustrate the distribution of the 54 vectors used in the false alarm calculation.

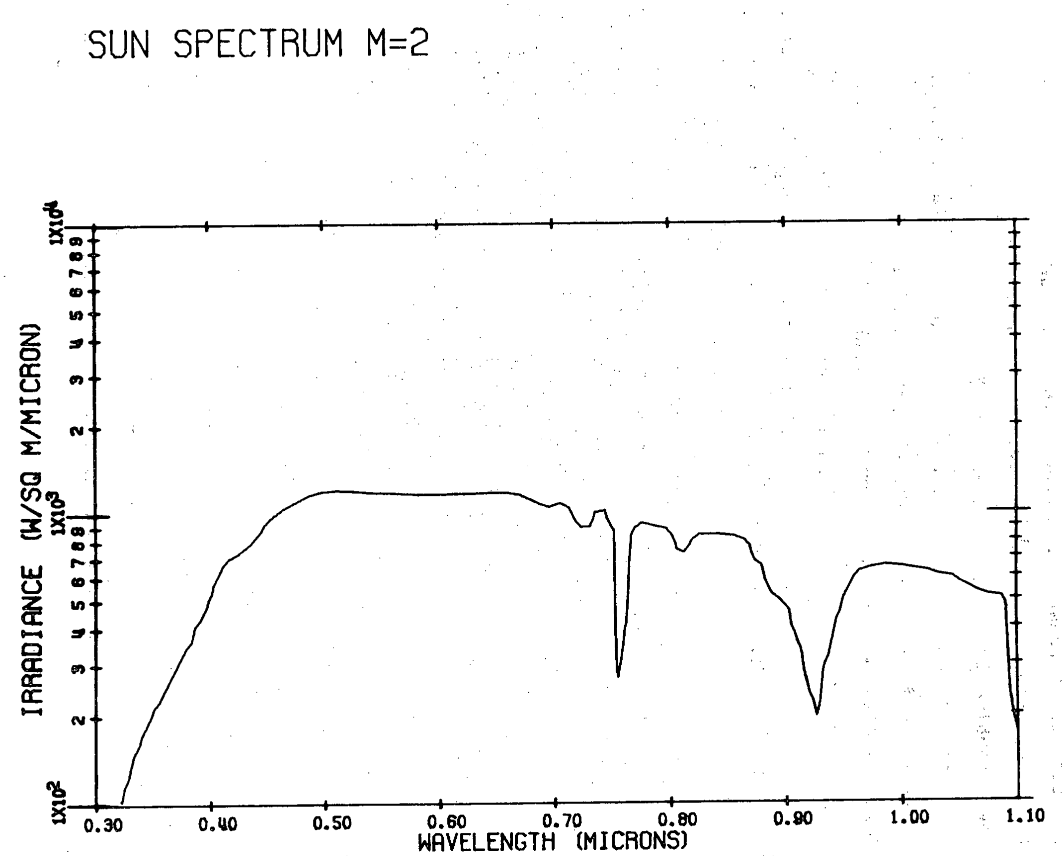

FIGURE B-1. SUN SPECTRUM USED IN CALCULATIONS FROM REFERENCE [11].

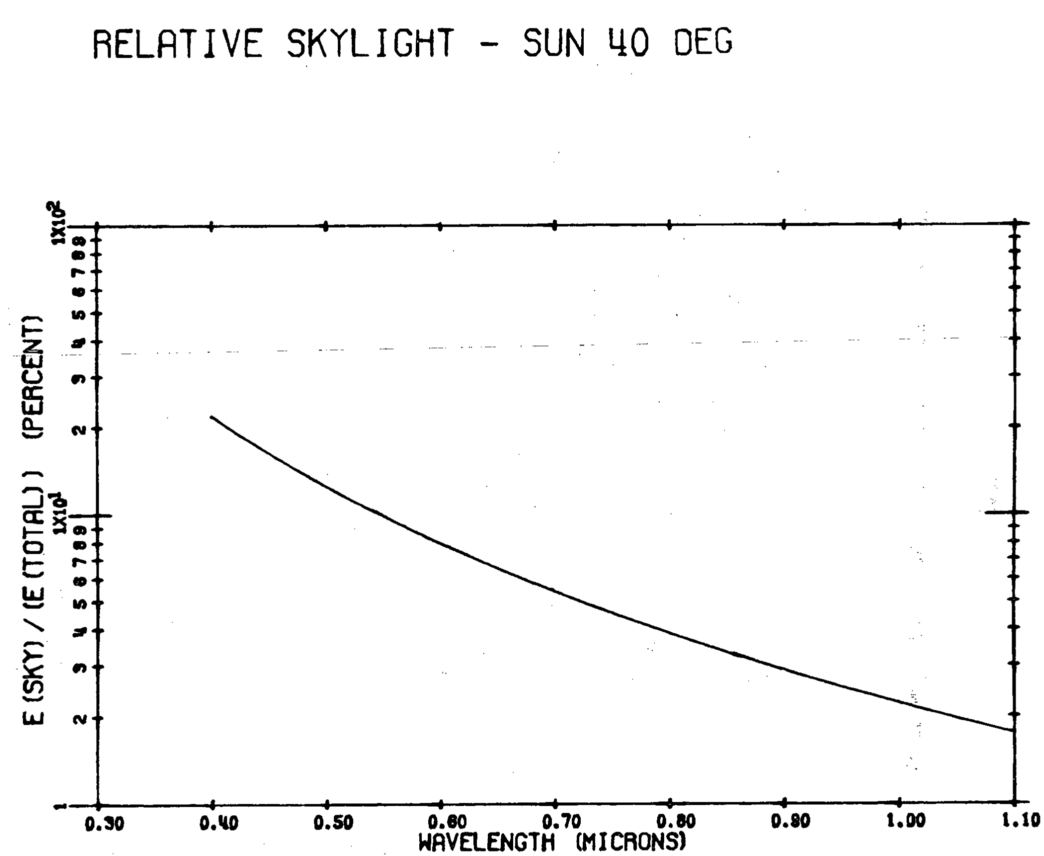

FIGURE B-2. REFLECTIVE SKY SPECTRUM USED IN CALCULATIONS FROM OBSERVATIONS OF G. SUITS.

TABLE B-1

WAVELENGTH BANDS USED FOR THE MULTISPECTRAL ANALYSIS

Band 1	0.456 - 0.481 μm
Band 2	0.531 - 0.556 μm
Band 3	0.631 - 0.668 μm
Band 4	0.806 - 0.893 μm

Declassified and Approved For Release 2012/08/06 : CIA-RDP98-00500R000200200001-7

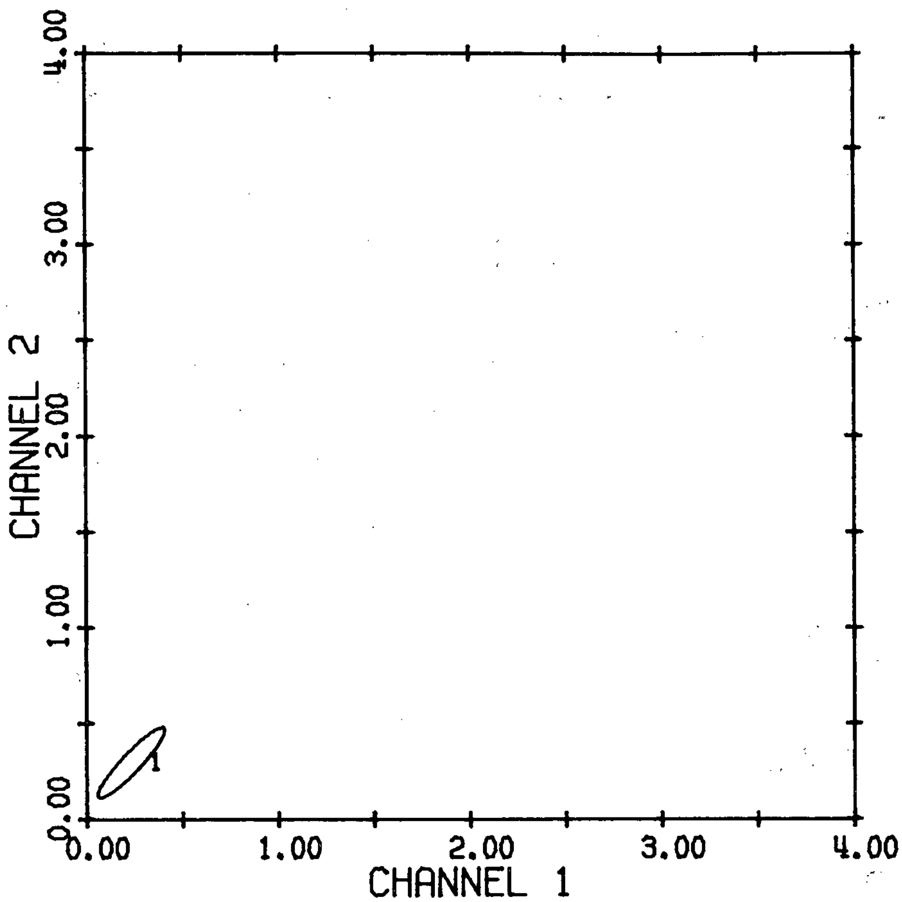

FIGURE B-3a. JOJOBA SIGNATURES FOR A PROBABILITY OF DETECTION OF 90% PROJECTED IN TWO DIMENSIONS.

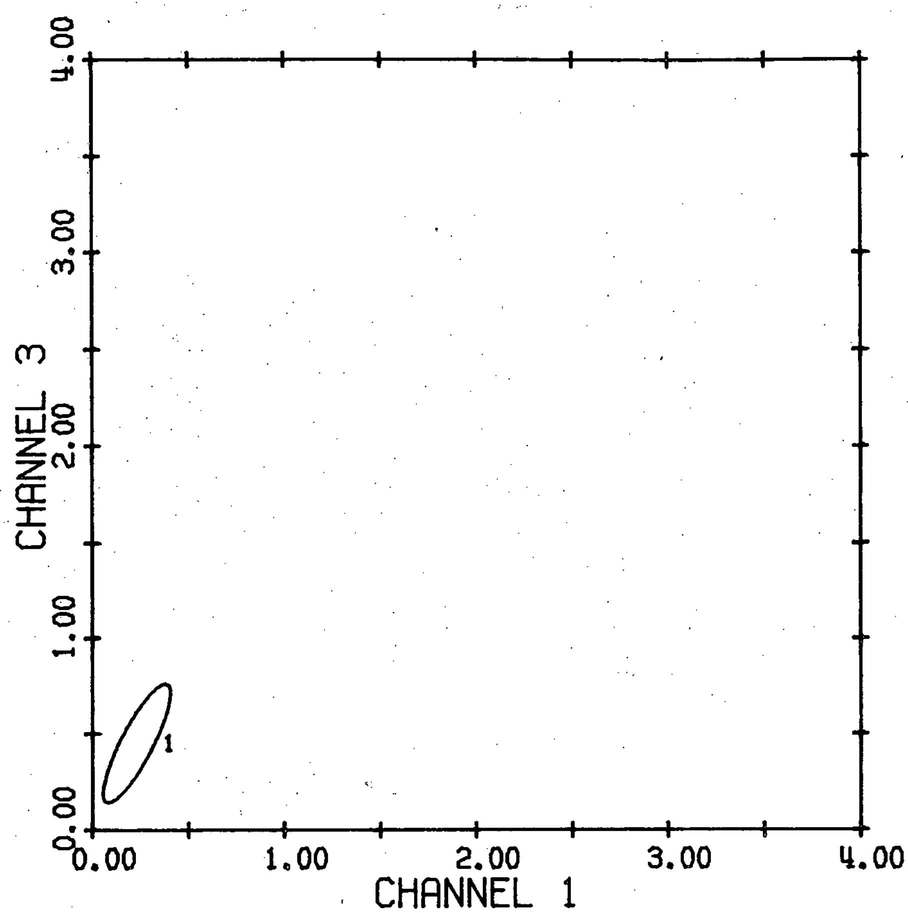

FIGURE B-3b. JOJOBA SIGNATURES FOR A PROBABILITY OF DETECTION OF 90% PROJECTED IN TWO DIMENSIONS.

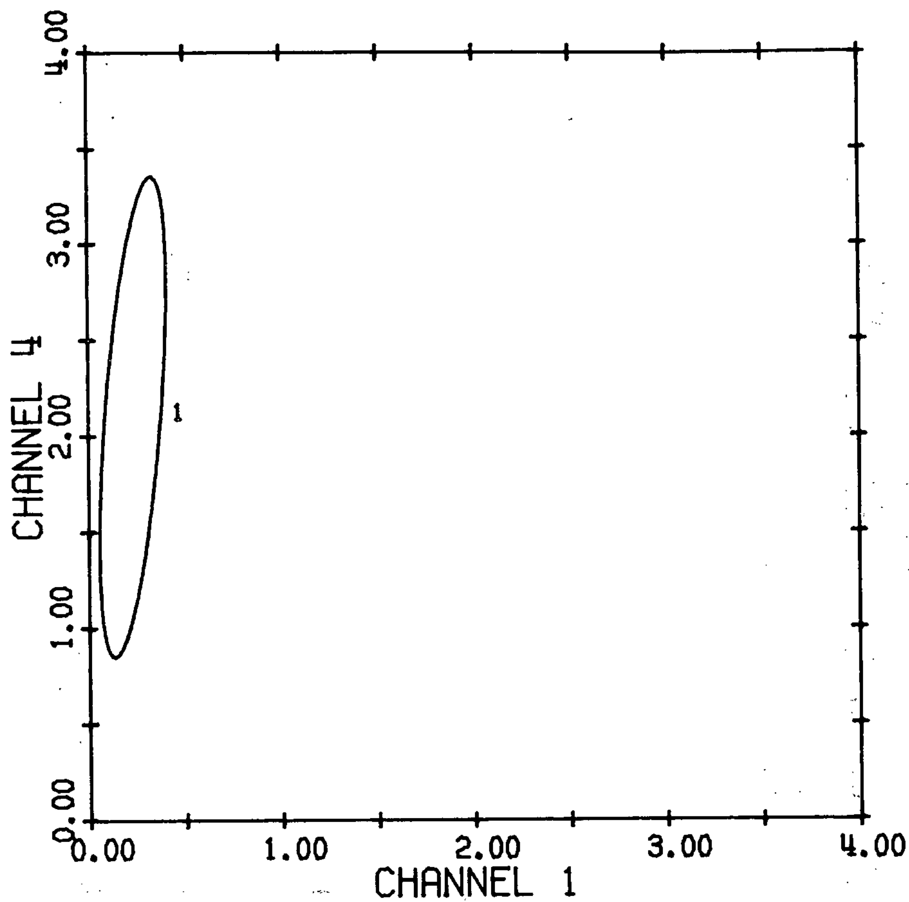

FIGURE B-3c. JOJOBA SIGNATURES FOR A PROBABILITY OF DETECTION OF 90% PROJECTED IN TWO DIMENSIONS.

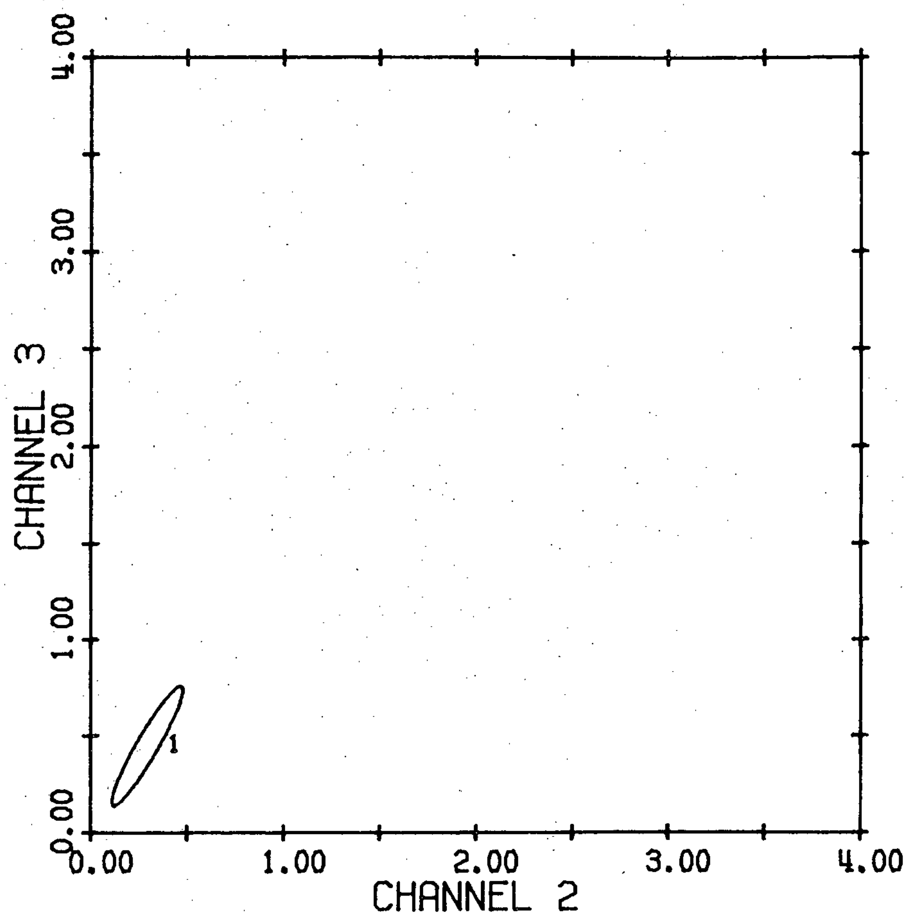

FIGURE B-3d. JOJOBA SIGNATURES FOR A PROBABILITY OF DETECTION OF 90% PROJECTED IN TWO DIMENSIONS.

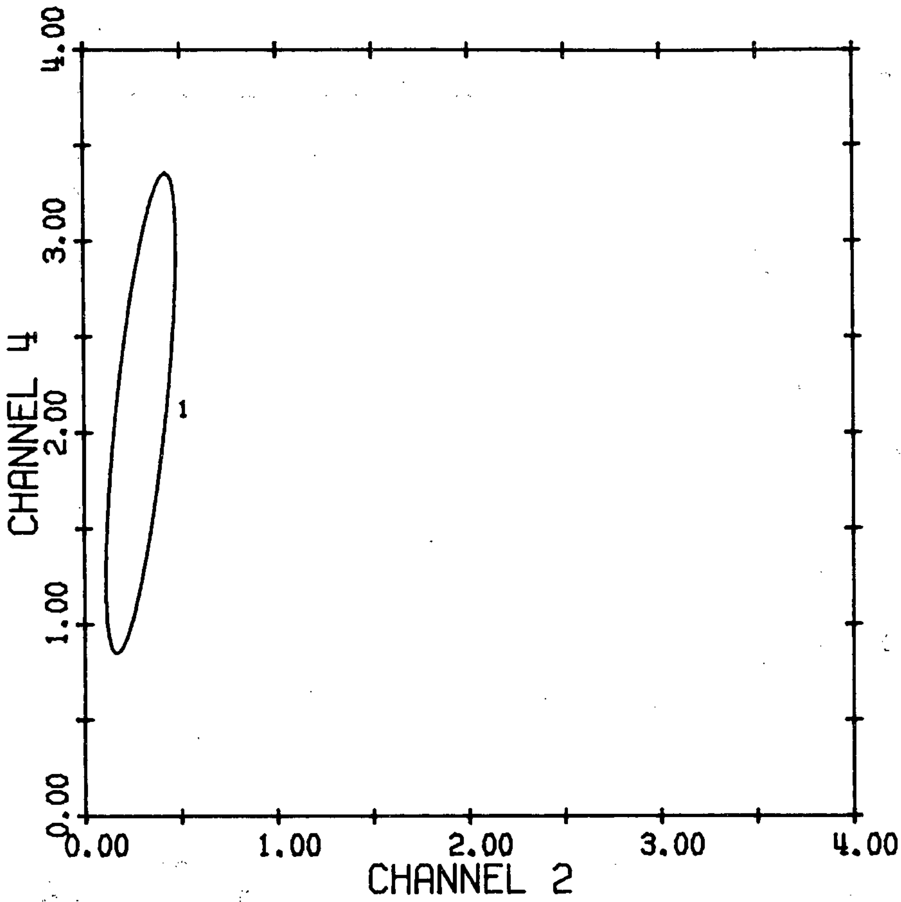

FIGURE B-3e. JOJOBA SIGNATURES FOR A PROBABILITY OF DETECTION OF 90% PROJECTED IN TWO DIMENSIONS.

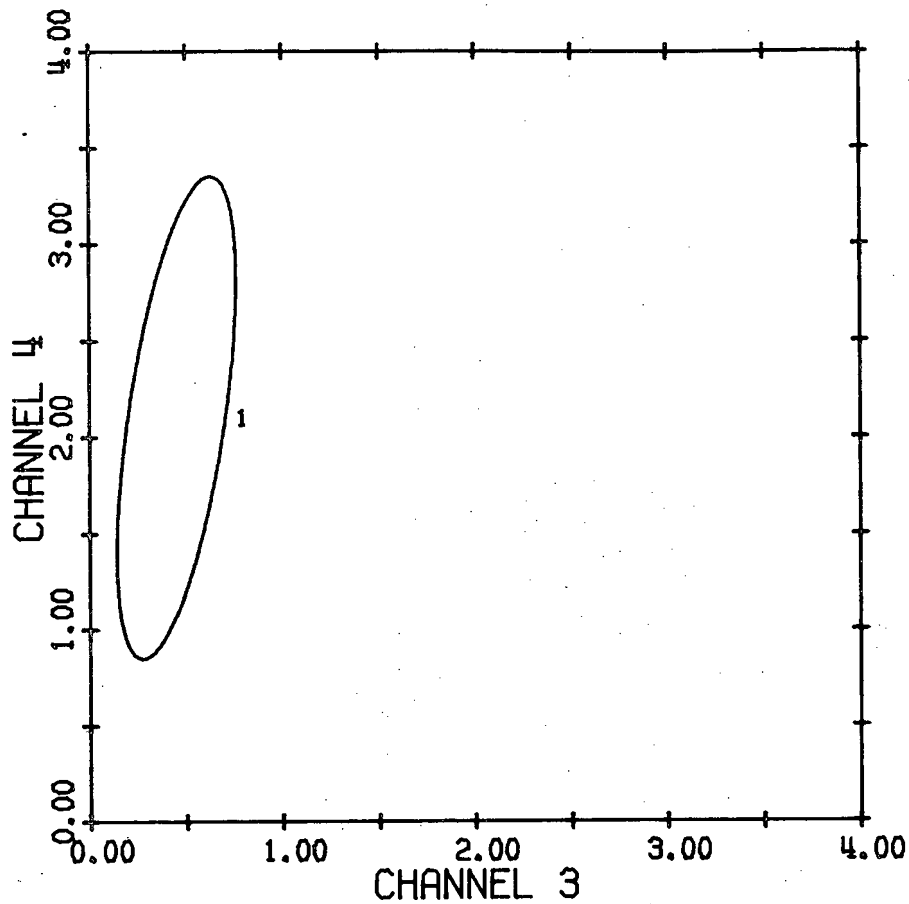

FIGURE B-3f. JOJOBA SIGNATURES FOR A PROBABILITY OF DETECTION OF 90% PROJECTED IN TWO DIMENSIONS.

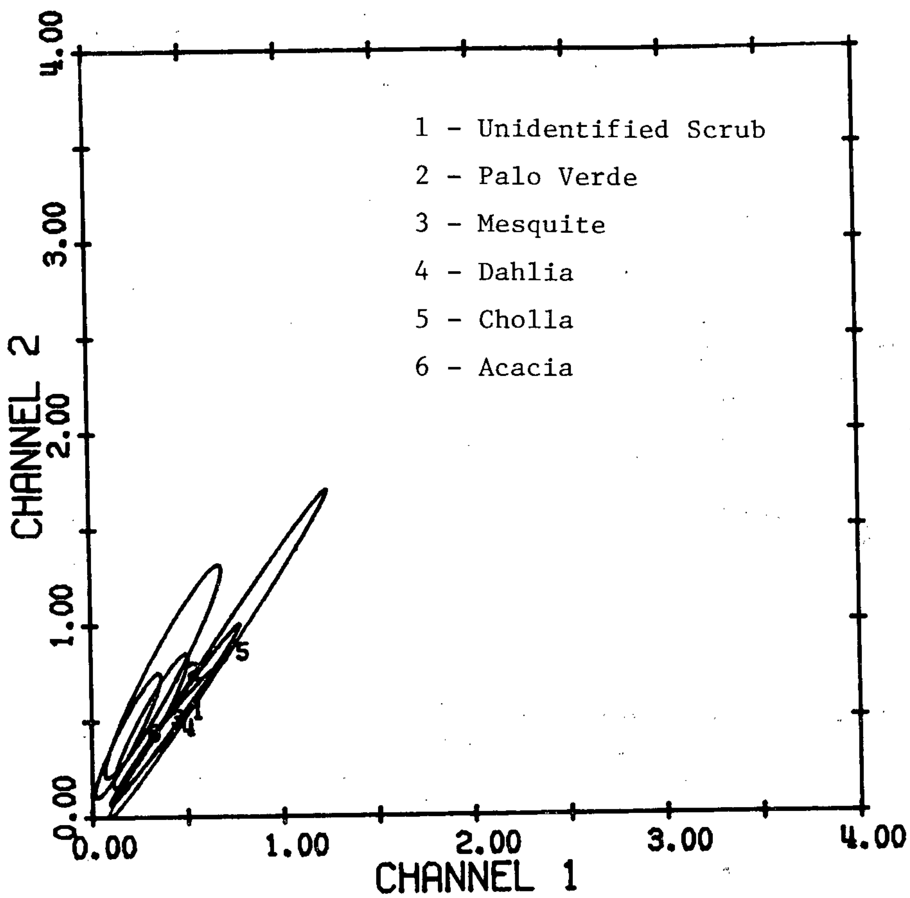

FIGURE B-4a. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

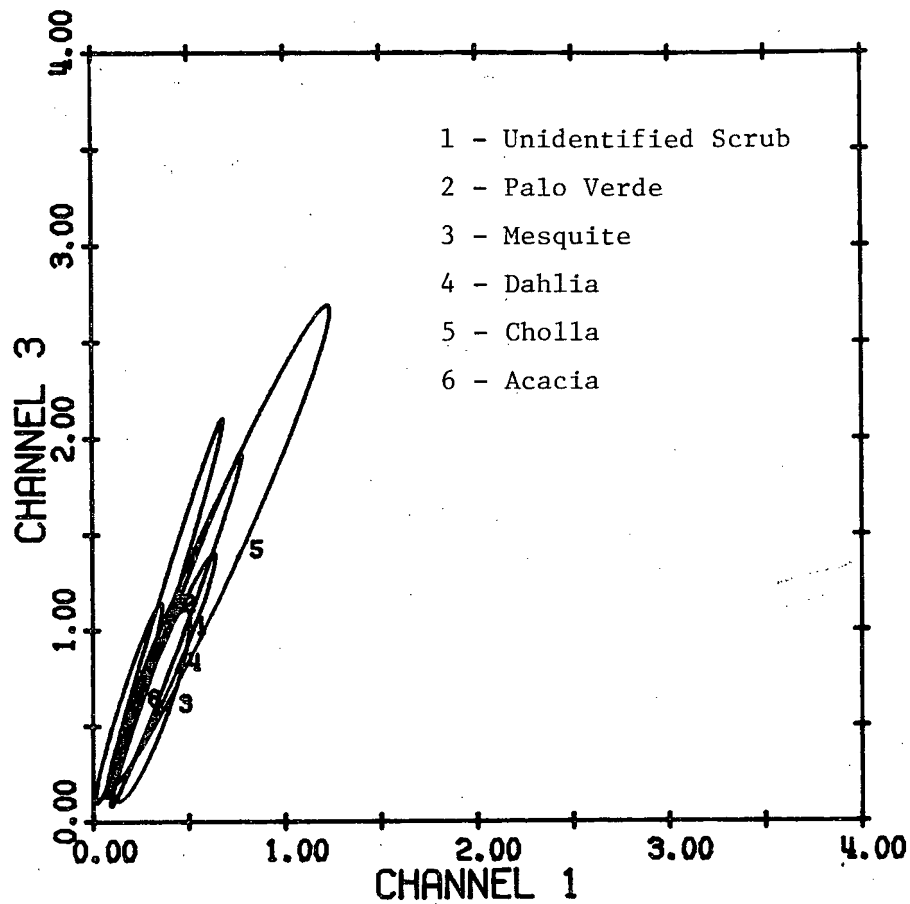

FIGURE B-4b. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

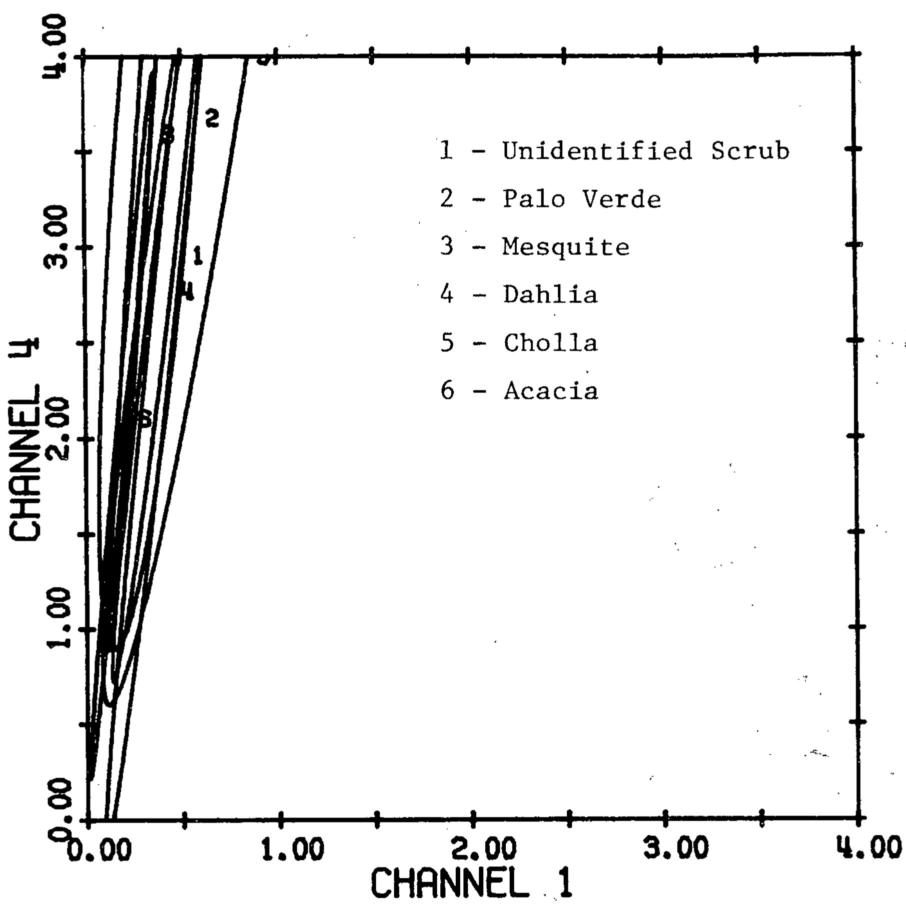

FIGURE B-4c. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

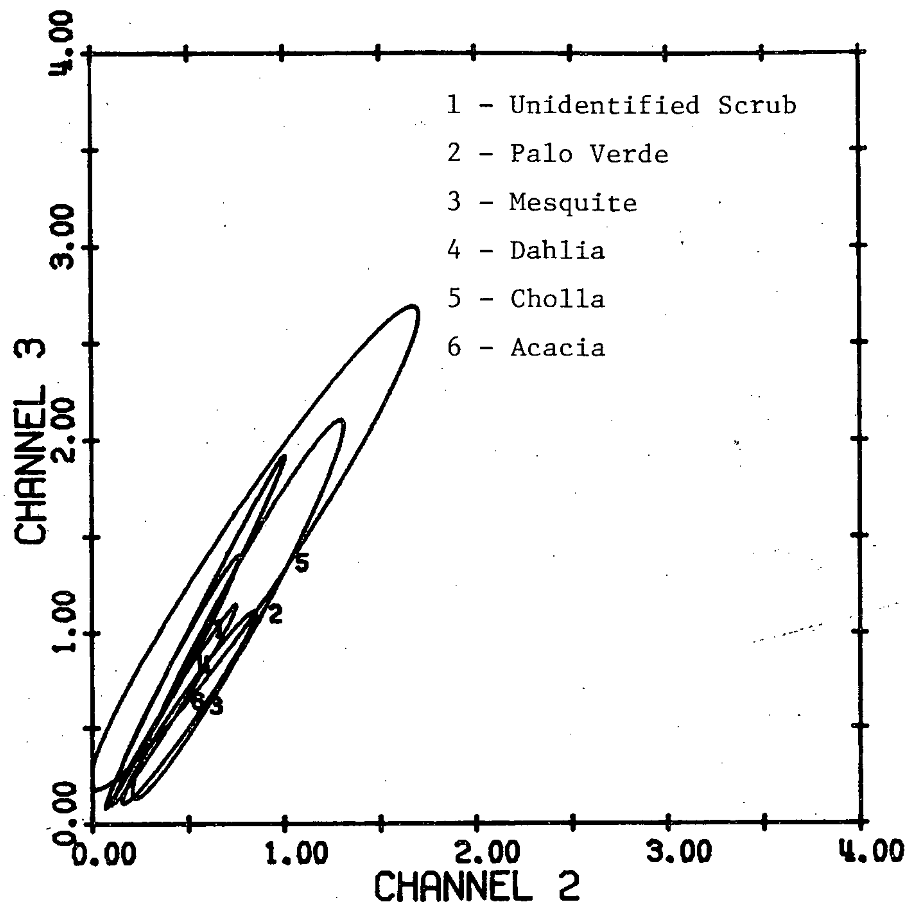

FIGURE B-4d. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

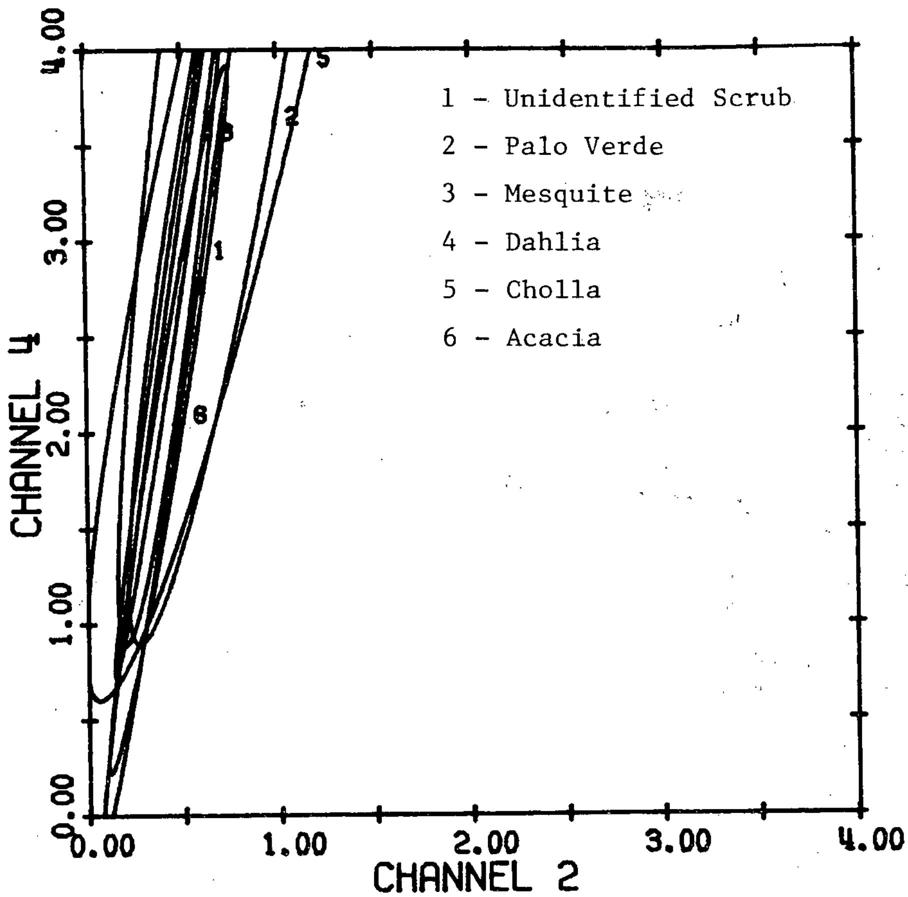

FIGURE B-4e. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

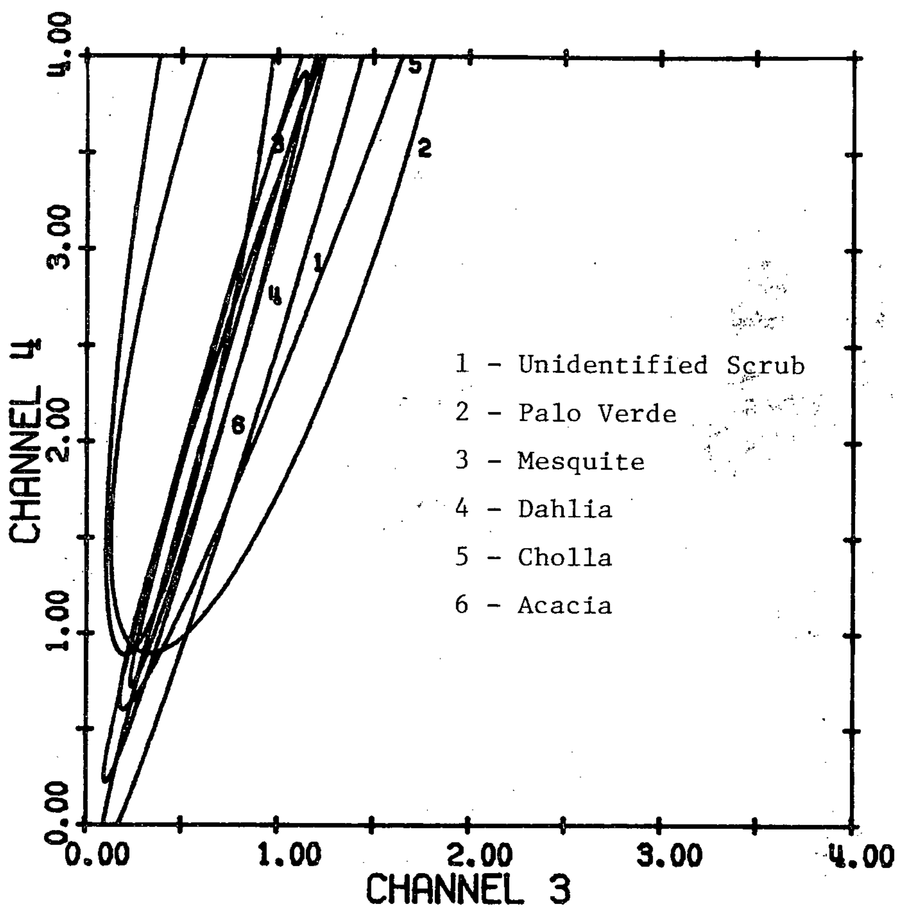

FIGURE B-4f. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

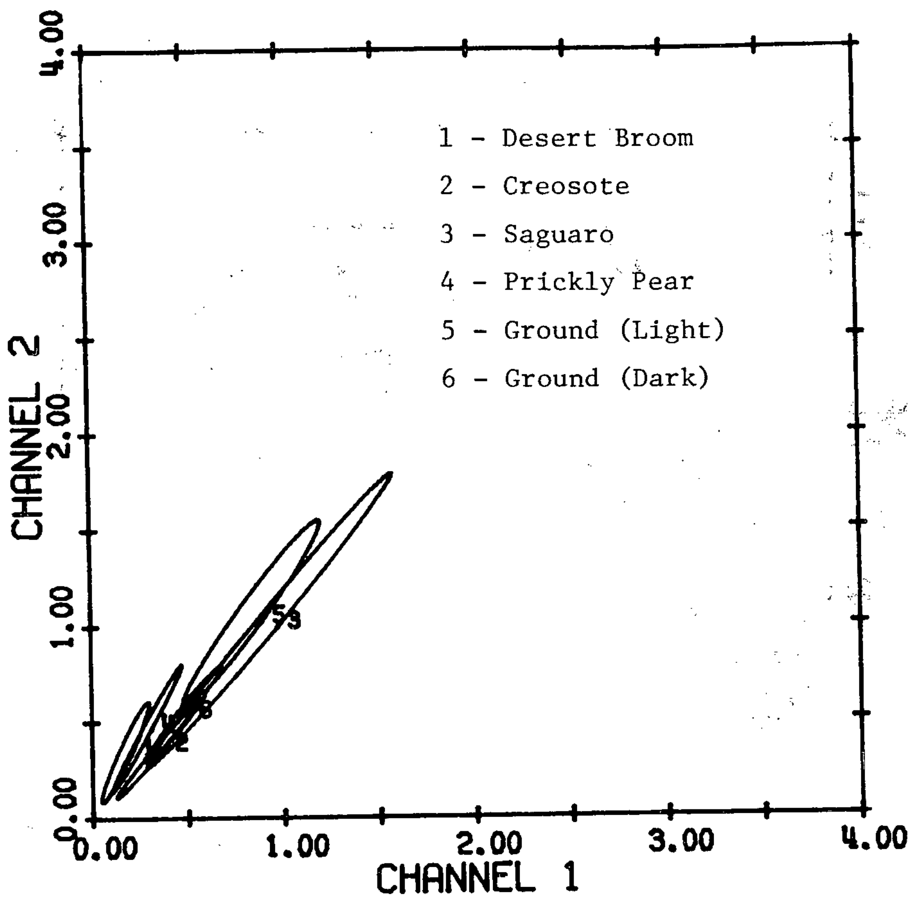

FIGURE B-5a. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

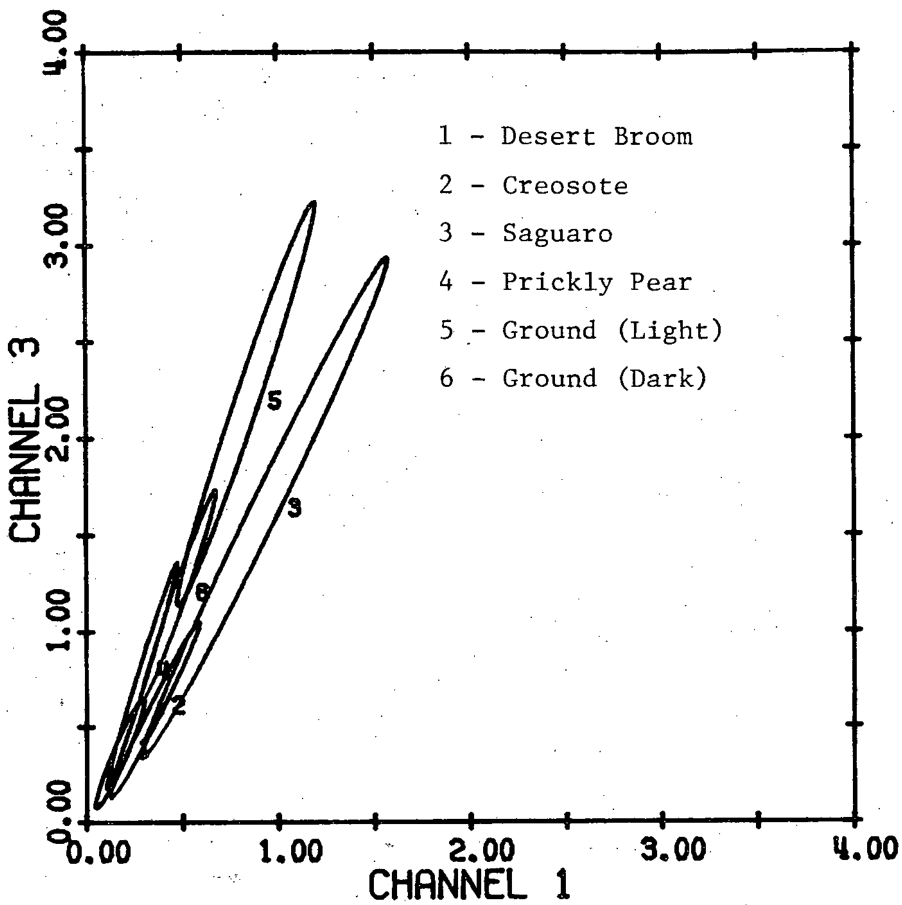

FIGURE B-5b. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

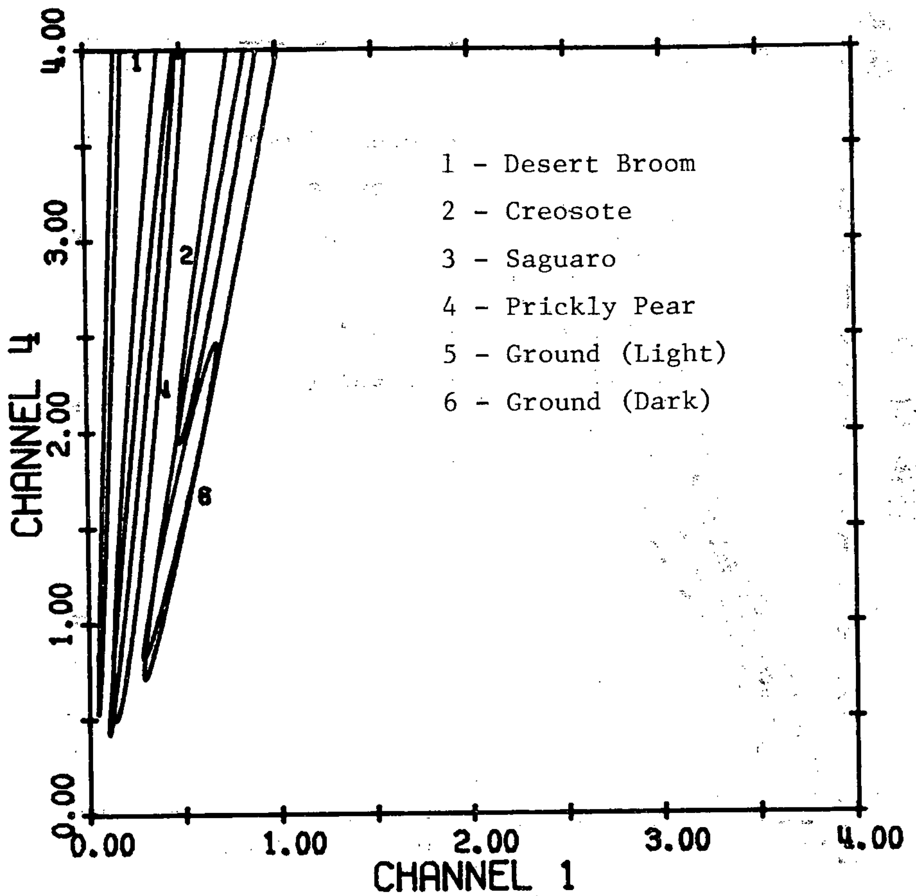

FIGURE B-5c. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

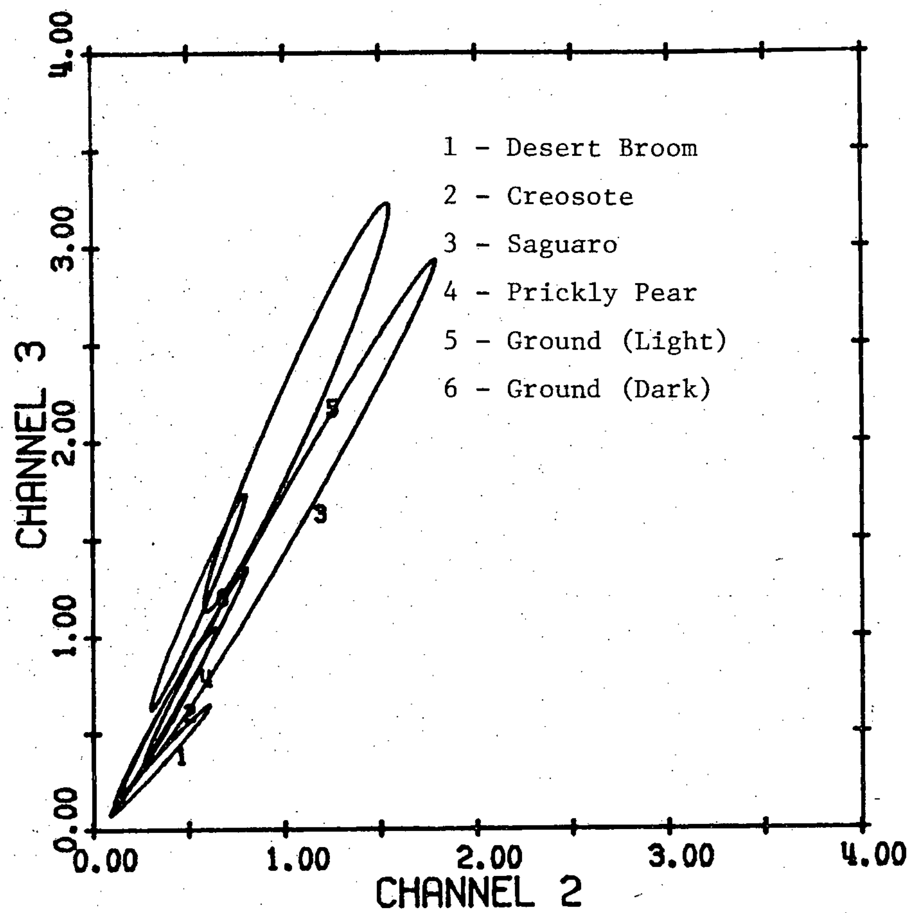

FIGURE B-5d. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

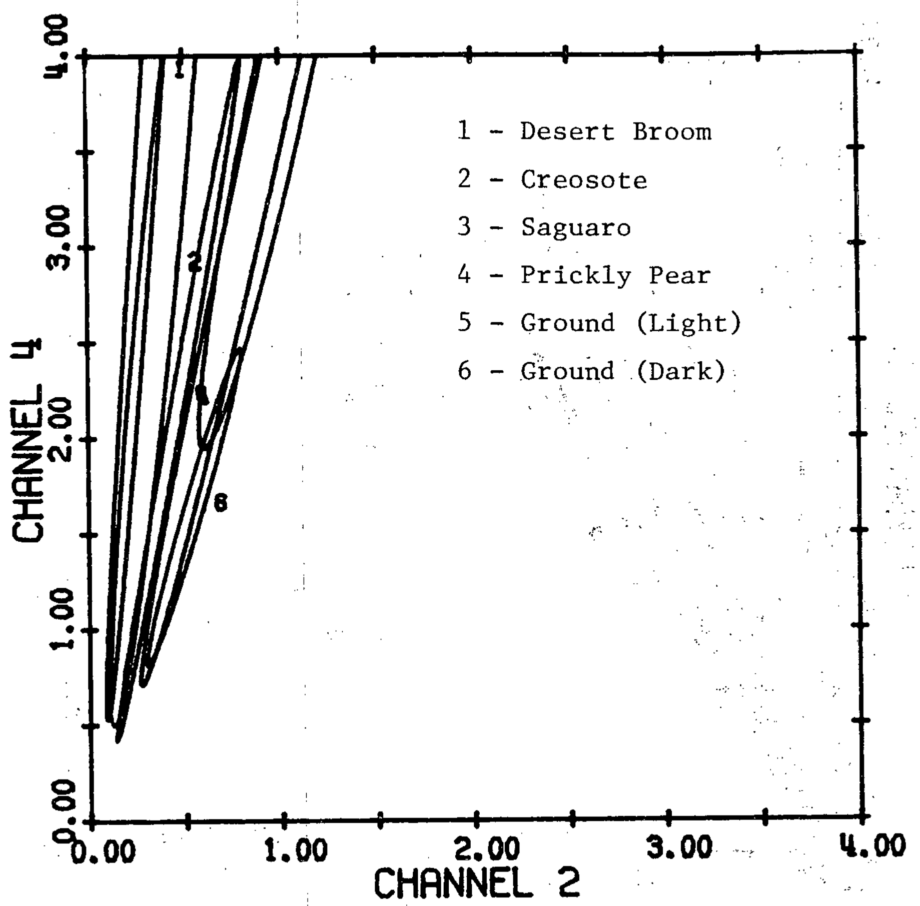

FIGURE B-5e. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

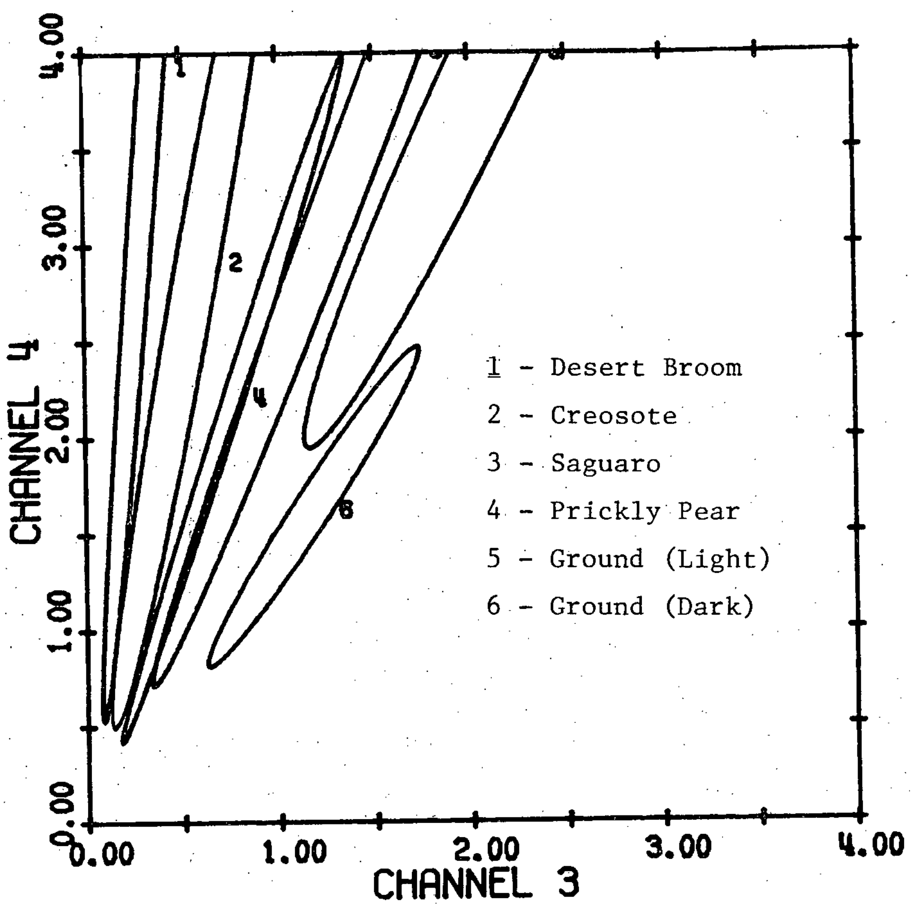

FIGURE B-5f. THE DISTRIBUTION AND PLACEMENT OF BACKGROUND 4-SPACE VECTORS USED IN THE DISCRIMINATION ANALYSIS.

APPENDIX C

FALSE ALARM CALCULATIONS

C-1 CALCULATIONAL PROCEDURE

The specifics of the probability of false alarm calculations are described in detail in this Appendix. An overall schematic of the calculation is shown in Figure C-1. Program LANDSAT carries out the calculation of band radiances described in Appendix B. ACLASS consists of 9 jojoba field measurements, BCLASS consists of 12 background field measurements including ten types of vegetation and two soils. These curves are shown in Section 3. The parameters used to generate 54 "sunlit" and 54 "shadowed" 4-space vectors from each of the field spectra are defined in Section 4.

The target vectors were analyzed to find the covariance and inverse covariance matrices. The covariance matrix is used to produce the ellipse plots in Appendix B and the inverse is used to find a transform matrix. This transform was found to simplify the calculations in FALARM and is described in Section C-3. It is estimated that the use of the transform cuts the computation time almost in half. The result of the transform is to change the coordinate system to one in which the decision boundary in a sphere centered at the origin rather than a four-dimensional ellipsoid centered away from the origin. The radius of the sphere is the square root of the chi-squared value corresponding to the desired probability of detection for four degrees of freedom. The data in BFILE, 12 species, sunlit and shadowed, each with 54 4-space vectors, is then transformed to the new coordinate system.

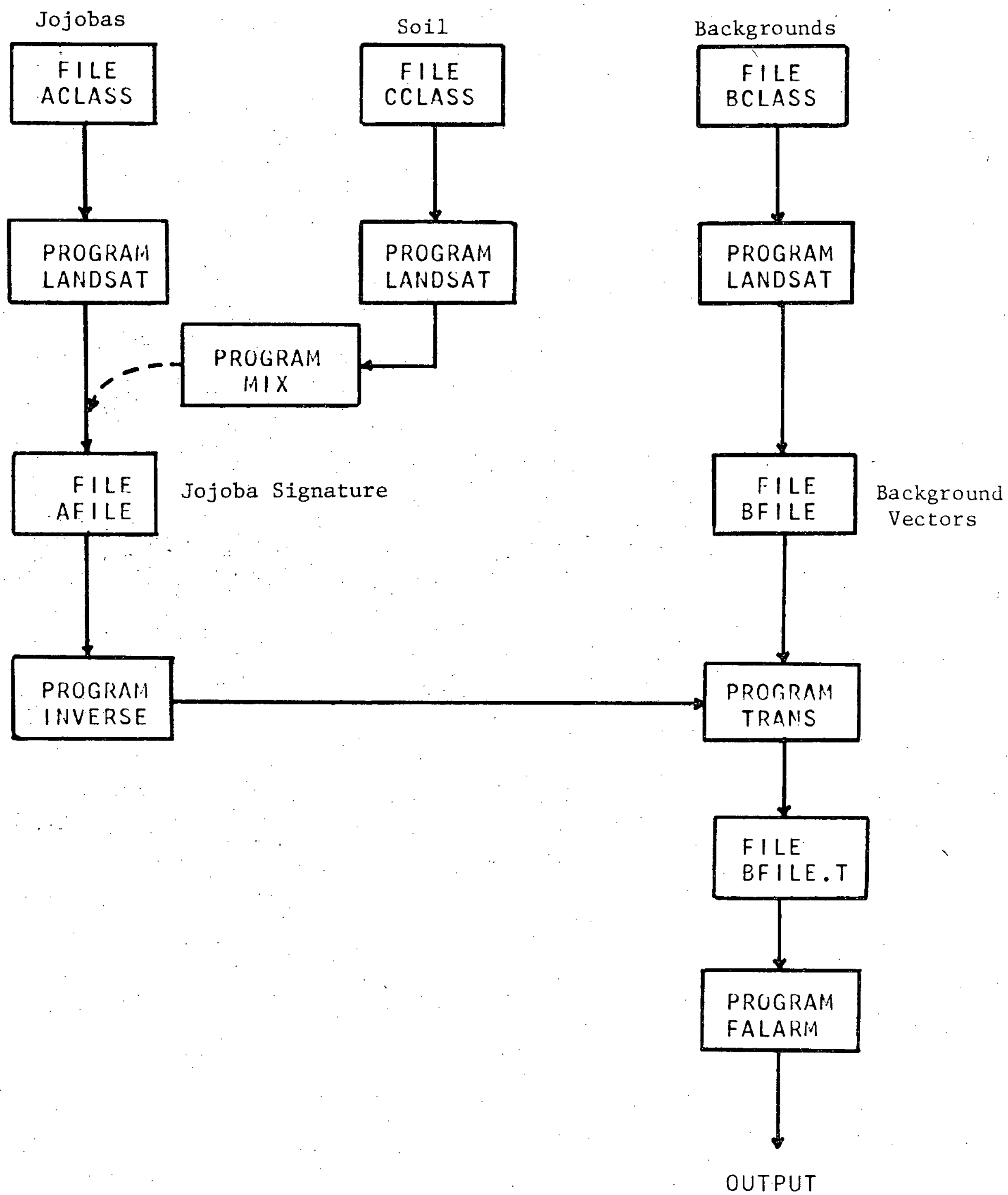

FIGURE C-1. FLOW DIAGRAM OF CALCULATION PROCEDURE

Program FALARM then calculates the length squared of each vector in the transformed BFILE and compares this with one or more chi-squared values. If the length squared is less than the chi-squared value, a false alarm is recorded. Linear combinations of the vectors in BFILE, representing mixed pixels, were also calculated. It was found that six combinations evenly spaced between all of one species and all of a second species were adequate to provide a good statistical check.

For the sunlit species, all 54 vectors are used; for the shadowed, which showed only a small deviation from the mean in any direction, only the mean value was used. A total of 1.4×10^6 vectors and linear combinations of vectors were checked for a possible detection.

C-2 DETECTION AND FALSE ALARM MATRICES

Probabilities of detection and false alarm are analyzed by considering each of the four-band spectra as a vector in a four-dimensional Cartesian coordinate system. A "target" space is defined by a four-dimensional ellipse centered about the mean of all of the target spectra. The principle axes of the ellipse are defined by the distribution of target spectra about the mean. The size of the ellipse determines the probability of detection (the number of target spectra included inside the ellipse) and the probability of false alarm (the number of background spectra included in the ellipse). The probability of false alarm from mixed background spectra is the fraction inside of the ellipse of all of the points generated by taking linear combinations of all of the spectra from one background class with all of those of another.

The probabilities of false alarm due to pure and mixed background spectra are shown in Tables C-2 and C-3. Table C-2 is a false alarm matrix for a detection probability of 90 percent, and Table C-3 a false alarm matrix for detection probability of 10 percent. Background classes in the false alarm matrices are numbered from 1 to 24 as specified in Table C-1. There are five false alarm entries for each mixture of background type M (a row in the table) and background type N (a column in the table). Each false alarm entry includes mixtures of

0, 20, 40, 60, 80, or 100 percent (a row index) of background type M with 100, 80, 60, 40, 20, or 0 percent of background type N. Each entry in the table is the percentage of spectra generated by taking the appropriate linear combinations of each of the 54 x 54 spectra of background that fall inside of the target ellipse. Diagonal elements in the matrix represent false alarms due to pure background spectra.

C-3 TRANSFORM ALGORITHM

When dealing with large numbers of calculations, it is helpful and economical to go about them in the simplest way possible. A very simple example would be instead of calculating 2A + 2B, to calculate 2(A + B).

A similar type of simplification can be done when comparing many points (and their linear combinations) to a quadratic form corresponding to an ellipse:

In general the quadratic form is

$$\underline{X}^T \underline{\underline{M}}\, \underline{X} = k$$

and in two dimensions it takes the form

$$ax^2 + 2\,bxy + cy^2 = k$$

the algorithm is as follows:

(1) Complete the square for the first term (the order is arbitrary) by adding and subtracting appropriate terms.

$$ax^2 + 2bxy + \left(\frac{b}{\sqrt{a}}\, y\right)^2 - \left(\frac{b}{\sqrt{a}}\, y\right)^2 + cy^2 = k$$

$$\left(\sqrt{a}\, x + \frac{b}{\sqrt{a}}\, y\right)^2 + \left(c - \frac{b}{\sqrt{a}}\right) y^2 = k$$

(2) Continue this until all cross terms have been eliminated.

(3) Then the substitution

$$x' = \sqrt{a}\, x + \frac{b}{\sqrt{a}}\, y$$

$$y' = \sqrt{c - \frac{b}{\sqrt{a}}}\, y$$

yields $(x')^2 + (y')^2 = k$.

As a further example, the first step for three dimensions is shown below:

$$a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 = k$$

$$\left(\sqrt{a_{11}}\, x_1 + \frac{a_{12}}{2\sqrt{a_{11}}}\, x_2 + \frac{a_{13}}{2\sqrt{a_{11}}}\, x_3\right)^2 + \left(a_{22} - \frac{a_{12}^2}{4a_{11}}\right) x_2^2 + \left(a_{33} - \frac{a_{13}^2}{4a_{11}}\right) x_3^2$$

$$+ \left(a_{23} - \frac{a_{13}a_{12}}{2a_{11}}\right) x_2x_3 = k$$

so $$x' = \sqrt{a_{11}}\, x_1 + \frac{a_{12}}{2\sqrt{a_{11}}}\, x_2 + \frac{a_{13}}{2\sqrt{a_{11}}}\, x_3$$

The Fortran program is given which carries out the calibration in n-dimensions.

In general, for n-dimensions, the first coordinate, x', will be a linear combination of n-coordinates, the second of (n - 1) coordinates and so on. Since the transform is linear, it may be performed before linear combinations of the points creating mixtures are considered. That is, if the transform is designed by the upper triangular matrix T,

$$[\underline{\underline{T}}(\underline{X} + \underline{Y})]^T \underline{\underline{M}}[\underline{\underline{T}}(\underline{X} + \underline{Y})] = (\underline{\underline{T}}\underline{X} + \underline{\underline{T}}\underline{Y})^T \underline{\underline{M}}(\underline{\underline{T}}\underline{X} + \underline{\underline{T}}\underline{Y})$$

FORTRAN IV TRANSFORMATION PROGRAM LISTING

```
C
      SUBROUTINE SPHERE(N,A,B)
C
C     TRANSFORMATION OF AN N-DIMENSIONAL ELLIPSOID
C     TO AN N-DIMENSIONAL SPHERE.
C
C     INPUTS INCLUDE: N = NO. OF DIMENSIONS
C                     A(I,J) = INVERSE COVARIANCE MATRIX
C                     B(I,J) = TRANSFORM MATRIX
C
C     NOTE: THIS IS NOT A ROTATION BUT A CONTORTION
C
      DIMENSION A(4,4),B(4,4)
      NAMELIST/DUMP/A,B,I,K,L,J
      INTEGER C1,C2,C3
C
      IF(N.LT.2)GOTO 60
      C3=N-1
      DO 10 L=2,N
      C1=L-1
      DO 10 K=1,C1
   10 B(L,K)=0.
C
      DO 50 I=1,C3
      C2=I+1
      IF(A(I,I).LE.0.)GOTO 70
      B(I,I)=SQRT(A(I,I))
      DO 20 J=C2,N
   20 B(I,J)=A(I,J)/B(I,I)
      DO 30 K=C2,N
      DO 30 L=C2,K
   30 A(L,K)=A(L,K)-A(I,K)*A(I,L)/A(I,I)
   50 CONTINUE
   60 IF(A(N,N).LE.0.)GOTO 70
      B(N,N)=SQRT(A(N,N))
      RETURN
C
   70 WRITE(6,80)
   80 FORMAT(' NOT AN ELLIPSOID',/)
      WRITE(6,DUMP)
      END
END OF FILE
```

TABLE C-1

BACKGROUND IDENTIFICATION NUMBERS
IN FALSE ALARM MATRICES

1	Sunlit Unidentified Scrub
2	Shadowed Unidentified Scrub
3	Sunlit Palo Verde
4	Shadowed Palo Verde
5	Sunlit Mesquite
6	Shadowed Mesquite
7	Sunlit Dahlia
8	Shadowed Dahlia
9	Sunlit Cholla
10	Shadowed Cholla
11	Sunlit Acacia
12	Shadowed Acacia
13	Sunlit Desert Broom
14	Shadowed Desert Broom
15	Sunlit Creosote
16	Shadowed Creosote
17	Sunlit Saguaro
18	Shadowed Saguaro
19	Sunlit Prickly Pear
20	Shadowed Prickly Pear
21	Sunlit Ground
22	Shadowed Ground
23	Sunlit Ground
24	Shadowed Ground

TABLE C-2. PROBABILITY OF DETECTION SET EQUAL TO 90 PERCENT

FALSE ALARM MATRIX 1 r = 7.78

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1 Scrub																								
0.0	20.4	0.0	0.0	0.0	1.9	0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20	22.6	57.4	0.0	46.3	14.7	55.6	29.8	61.1	5.6	57.4	5.9	55.6	23.4	79.6	47.6	59.3	0.0	31.5	15.4	63.0	0.0	44.4	0.0	48.1
0.40	19.9	87.0	1.9	23.3	22.8	87.0	25.0	87.0	4.6	87.0	10.5	87.0	39.0	90.7	44.0	87.0	1.3	70.4	10.9	88.9	0.0	75.9	0.0	81.5
0.60	19.9	53.7	5.3	57.4	35.6	61.1	25.8	53.7	8.2	53.7	16.4	57.4	50.1	61.1	39.2	55.6	4.5	55.6	27.8	59.3	0.0	53.7	1.0	51.9
0.80	22.6	40.7	16.0	42.6	42.4	42.6	25.3	40.7	15.0	40.7	33.3	42.6	46.3	42.6	34.5	40.7	12.9	40.7	30.6	42.6	2.5	40.7	7.9	40.7
1.00	20.4	20.4	20.4	20.4	20.4	20.4	20.3	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
2																								
0.0		0.0	0.0	0.0	1.9	0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	1.9	0.0	55.6	0.0	7.4	0.0	0.0	0.0	11.1	0.0	59.3	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	13.0	0.0	77.8	0.0	14.8	0.0	0.0	0.0	37.0	0.0	79.6	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	46.3	0.0	83.0	0.0	35.2	0.0	11.1	0.0	74.1	0.0	87.0	0.0	0.0	0.0	63.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	1.9	0.0	88.1	0.0	72.2	0.0	48.1	0.0	18.5	0.0	74.1	0.0	50.0	0.0	1.9	0.0	38.9	0.0	7.4	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 Palo Verde																								
0.0			0.0	0.0	1.9	0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.2	0.0	29.4	5.6	6.5	1.9	0.0	0.0	0.7	0.0	59.3	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
0.40			0.0	0.0	0.0	0.0	11.4	0.0	2.4	0.0	0.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
0.60			0.0	0.0	0.0	0.0	7.1	0.0	2.4	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
0.80			0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4																								
0.0				0.0	1.9	0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	61.8	0.0	9.3	0.0	0.0	0.0	5.6	0.0	75.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	87.0	0.0	24.1	0.0	0.0	0.0	5.6	0.0	85.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	88.9	0.0	37.0	0.0	0.0	0.0	25.9	0.0	88.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	48.1	0.0	38.9	0.0	0.0	0.0	5.6	0.0	44.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 Mesquite																								
0.0					1.9	0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20					1.7	3.7	51.1	70.4	10.6	63.0	0.0	7.4	5.1	22.2	64.5	63.0	0.0	0.0	5.1	20.4	0.0	9.3	5.9	70.4
0.40					0.5	5.6	52.3	51.9	13.4	50.0	0.0	16.7	1.6	25.9	56.0	50.0	0.7	5.6	3.8	29.6	0.0	24.1	10.5	53.7
0.60					0.3	0.0	28.9	16.7	12.4	16.7	0.2	5.6	1.4	5.6	25.6	14.8	0.9	1.9	3.8	5.6	2.1	5.6	23.4	18.5
0.80					1.7	0.0	15.8	1.9	9.3	1.9	1.1	0.0	2.8	0.0	13.8	1.9	3.9	0.0	4.1	1.9	9.6	1.9	18.8	5.6
1.00					1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
6																								
0.0						0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20						0.0	61.8	0.0	9.3	0.0	0.0	0.0	5.6	0.0	68.5	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0
0.40						0.0	85.2	0.0	24.1	0.0	0.0	0.0	11.1	0.0	81.5	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0
0.60						0.0	88.9	0.0	37.0	0.0	0.0	0.0	27.8	0.0	88.9	0.0	0.0	0.0	11.1	0.0	3.7	0.0	0.0	0.0
0.80						0.0	72.2	0.0	42.6	0.0	0.0	0.0	11.1	0.0	50.0	0.0	9.3	0.0	1.9	0.0	40.7	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ERIM

FORMERLY WILLOW RUN LABORATORIES, THE UNIVERSITY OF MICHIGAN

TABLE C-2. (Continued)

7 Dahlia																		
0.0	24.1	0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20	26.9	74.1	5.8	74.1	7.4	74.1	23.8	83.3	47.7	74.1	0.0	1.9	20.2	77.8	0.0	35.2	0.0	55.6
0.40	27.5	88.9	8.2	88.9	16.9	88.9	44.1	88.9	47.4	88.9	6.2	85.2	33.8	88.9	0.0	88.9	0.1	88.9
0.60	27.5	75.9	10.5	77.8	38.7	85.2	61.3	88.9	42.7	77.8	8.1	74.1	44.3	85.2	0.2	77.8	1.7	74.1
0.80	26.9	55.6	18.0	55.6	46.2	63.0	56.0	63.0	35.0	57.4	16.9	55.6	39.4	59.3	4.1	55.6	10.5	51.9
1.00	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1
8																		
0.0		0.0	5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20		0.0	7.4	0.0	0.0	0.0	11.1	0.0	59.3	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0
0.40		0.0	14.8	0.0	0.0	0.0	37.0	0.0	77.8	0.0	0.0	0.0	29.6	0.0	0.0	0.0	0.0	0.0
0.60		0.0	35.2	0.0	13.0	0.0	74.1	0.0	87.0	0.0	1.9	0.0	77.8	0.0	0.0	0.0	0.0	0.0
0.80		0.0	66.7	0.0	22.2	0.0	75.9	0.0	55.6	0.0	44.4	0.0	46.3	0.0	24.1	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 Cholla																		
0.0			5.6	0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20			4.5	50.9	4.8	46.3	15.0	51.9	37.3	68.5	0.0	9.3	9.3	46.3	0.0	35.2	0.0	50.0
0.40			2.2	35.2	6.2	37.0	18.7	40.7	17.9	35.2	0.4	33.3	9.5	37.0	0.0	35.2	0.0	31.5
0.60			2.2	14.8	8.2	24.1	15.0	24.1	11.1	18.5	0.9	11.1	8.6	22.2	0.0	13.0	0.1	11.1
0.80			4.5	7.4	8.9	7.4	10.9	7.4	6.3	7.4	3.9	7.4	6.7	7.4	0.5	7.4	0.8	7.4
1.00			5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
10																		
0.0				0.0	0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	11.1	0.0	59.3	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	37.0	0.0	77.8	0.0	0.0	0.0	24.1	0.0	0.0	0.0	0.0	0.0
0.60				0.0	11.1	0.0	75.9	0.0	87.0	0.0	0.0	0.0	74.1	0.0	0.0	0.0	0.0	0.0
0.80				0.0	20.4	0.0	75.9	0.0	53.7	0.0	7.4	0.0	40.7	0.0	7.4	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 Acacia																		
0.0					0.0	0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	2.6	1.9	76.9	24.1	0.0	0.0	0.1	1.9	0.0	1.9	0.0	24.1
0.40					0.0	0.0	0.6	0.0	67.6	14.8	0.1	5.6	0.0	0.0	0.0	0.0	0.6	14.8
0.60					0.0	0.0	0.5	0.0	26.8	1.9	0.1	0.0	0.0	0.0	0.2	0.0	0.9	1.9
0.80					0.0	0.0	0.4	0.0	8.7	0.0	0.7	0.0	0.0	0.0	0.6	0.0	2.2	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12																		
0.0						0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20						0.0	5.6	0.0	70.4	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0
0.40						0.0	14.8	0.0	81.5	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0
0.60						0.0	35.2	0.0	88.9	0.0	3.7	0.0	11.1	0.0	3.7	0.0	0.0	0.0
0.80						0.0	18.5	0.0	57.4	0.0	38.9	0.0	1.9	0.0	20.4	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ERIM

TABLE C-2. (Continued)

13 Desert Broom												
0.0	5.6	0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20	6.5	42.6	58.6	68.5	4.8	5.6	12.6	51.9	0.0	55.6	9.4	75.9
0.40	2.8	44.4	55.9	72.2	8.1	55.6	11.7	57.4	0.8	72.2	19.7	81.5
0.60	2.8	16.7	35.0	33.3	8.3	29.6	11.4	25.9	5.3	35.2	51.5	42.6
0.80	6.5	5.6	21.2	9.3	16.5	7.4	10.5	5.6	19.1	11.1	30.1	13.0
1.00	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
14												
0.0		0.0	40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20		0.0	66.7	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0
0.40		0.0	81.5	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	87.0	0.0	5.6	0.0	44.4	0.0	9.3	0.0	0.0	0.0
0.80		0.0	74.1	0.0	59.3	0.0	24.1	0.0	74.1	0.0	66.7	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 Creosote												
0.0			40.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20			44.5	46.3	0.4	0.0	27.5	59.3	0.0	35.2	0.1	40.7
0.40			45.1	87.0	5.1	50.0	60.1	87.0	0.0	79.6	4.0	83.3
0.60			45.1	77.8	9.8	72.2	77.2	81.5	2.8	81.5	8.6	72.2
0.80			44.5	57.4	27.3	51.9	69.7	68.5	17.7	59.3	38.8	57.4
1.00			40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7
16												
0.0				0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	40.7	0.0	0.0	0.0	0.0	0.0
0.60				0.0	3.7	0.0	79.6	0.0	3.7	0.0	0.0	0.0
0.80				0.0	44.4	0.0	46.3	0.0	57.4	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 Saguaro												
0.0					0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	2.6	14.8	0.0	0.0	0.0	5.6
0.40					0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
0.60					0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
0.80					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18												
0.0						0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20						0.0	5.6	0.0	0.0	0.0	0.0	0.0
0.40						0.0	16.7	0.0	0.0	0.0	0.0	0.0
0.60						0.0	31.5	0.0	0.0	0.0	0.0	0.0
0.80						0.0	1.9	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE C-2. (Concluded)

19 Prickly Pear						
0.0	1.9	0.0	0.0	0.0	0.0	0.0
0.20	1.3	5.6	0.0	3.7	0.0	40.7
0.40	1.0	31.5	0.0	14.8	0.1	79.6
0.60	1.0	9.3	0.1	7.4	2.1	37.0
0.80	1.3	3.7	1.5	3.7	7.4	9.6
1.00	1.9	1.9	1.9	1.9	1.9	1.9
20						
0.0		0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0
0.80		0.0	24.1	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0
21 Ground (Light)						
0.0			0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	1.9
0.40			0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0
22						
0.0				0.0	0.0	0.0
0.20				0.0	0.0	0.0
0.40				0.0	0.0	0.0
0.60				0.0	0.0	0.0
0.80				0.0	0.0	0.0
1.00				0.0	0.0	0.0
23 Ground (Dark)						
0.0					0.0	0.0
0.20					0.0	0.0
0.40					0.0	0.0
0.60					0.0	0.0
0.80					0.0	0.0
1.00					0.0	0.0
24						
0.0						0.0
0.20						0.0
0.40						0.0
0.60						0.0
0.80						0.0
1.00						0.0

TABLE C-3. PROBABILITY OF DETECTION SET EQUAL TO 10 PERCENT

FALSE ALARM MATRIX 3 F = 1.06

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1 Scrub																								
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2																								
0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 Palo Verde																								
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40			0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4																								
0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 Mesquite																								
0.0					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	2.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40					0.0	0.6	2.9	0.0	0.5	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
0.60					0.0	0.0	3.4	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80					0.0	0.0	0.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6																								
0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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TABLE C-3. (Continued)

7 Dahlia																		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8																		
0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 Cholla																		
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40			0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10																		
0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 Acacia																		
0.0					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40					0.0	0.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60					0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80					0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12																		
0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60						0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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TABLE C-3. (Continued)

13 Desert Broom												
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
0.60	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
0.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14												
0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 Creosote												
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
0.40			0.0	0.0	0.0	0.0	4.9	0.0	0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16												
0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 Saguaro												
0.0					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18												
0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.40						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60						0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.80						0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00						0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE C-3. (Concluded)

19 Prickly Pear						
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	0.0	0.0
0.40	0.0	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.0	0.0
0.80	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0
20						
0.0		0.0	0.0	0.0	0.0	0.0
0.20		0.0	0.0	0.0	0.0	0.0
0.40		0.0	0.0	0.0	0.0	0.0
0.60		0.0	0.0	0.0	0.0	0.0
0.80		0.0	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.0	0.0	0.0
21 Ground (Light)						
0.0			0.0	0.0	0.0	0.0
0.20			0.0	0.0	0.0	0.0
0.40			0.0	0.0	0.0	0.0
0.60			0.0	0.0	0.0	0.0
0.80			0.0	0.0	0.0	0.0
1.00			0.0	0.0	0.0	0.0
22						
0.0				0.0	0.0	0.0
0.20				0.0	0.0	0.0
0.40				0.0	0.0	0.0
0.60				0.0	0.0	0.0
0.80				0.0	0.0	0.0
1.00				0.0	0.0	0.0
23 Ground (Dark)						
0.0					0.0	0.0
0.20					0.0	0.0
0.40					0.0	0.0
0.60					0.0	0.0
0.80					0.0	0.0
1.00					0.0	0.0
24						
0.0						0.0
0.20						0.0
0.40						0.0
0.60						0.0
0.80						0.0
1.00						0.0

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